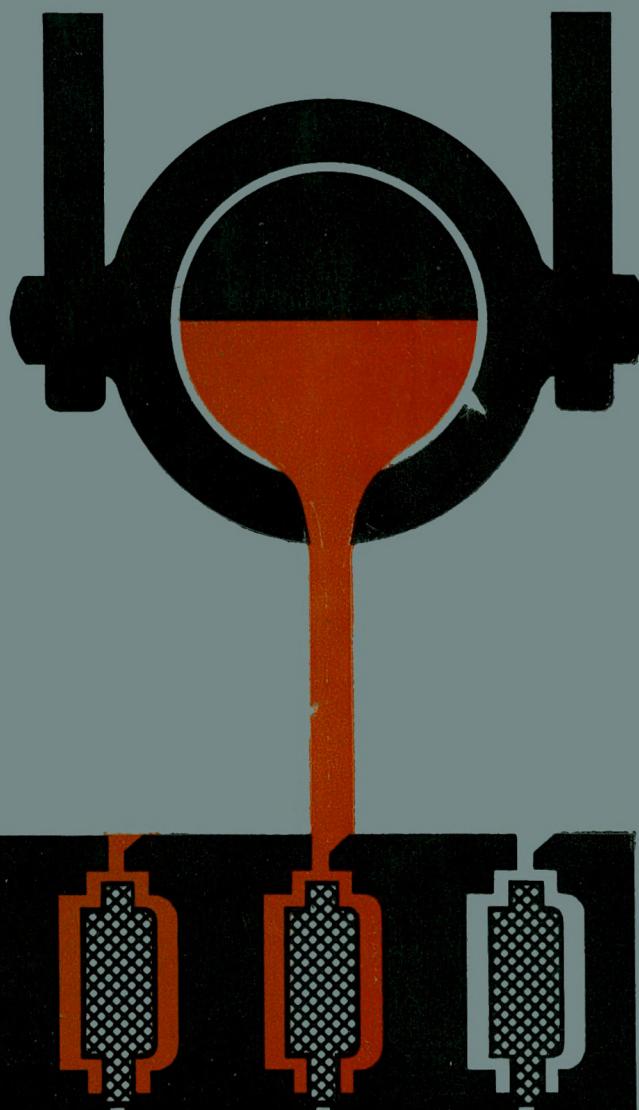


FOUNDRY PRACTICE

N. D. TITOV
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MIR
PUBLISHERS
MOSCOW



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**ТЕХНОЛОГИЯ
ЛИТЕЙНОГО
ПРОИЗВОДСТВА**

Москва · «Машиностроение»

N. D. Titov, Yu. A. Stepanov

FOUNDRY PRACTICE

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The Greek Alphabet

A α	Alpha	I ι	Iota	P ρ	Rho
B β	Beta	K κ	Kappa	S σ	Sigma
G γ	Gamma	Λ λ	Lambda	T τ	Tau
Δ δ	Delta	M μ	Mu	Υ υ	Upsilon
E ε	Epsilon	N ν	Nu	Φ φ	Phi
Z ζ	Zeta	Ξ ξ	Xi	Χ χ	Chi
H η	Eta	O ο	Omicron	Ψ ψ	Psi
Θ θ	Theta	Π π	Pi	Ω ω	Omega

The Russian Alphabet and Transliteration

А а	а	К к	к	Х х	kh
Б б	б	Л л	л	Ц ц	ts
В в	в	М м	м	Ч ч	ch
Г г	г	Н н	н	Ш ш	sh
Д д	д	О о	о	Щ щ	shch
Е е	е, ye	П п	р	Ь	"
Е ё	е	Р р	г	Ы	y
Ж ж	zh	С с	з	Ь	'
З з	z	Т т	т	Э э	e
И и	i	У у	и	Ю ю	ui
Й ў	y	Ф ф	f	Я я	ya

На английском языке

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PREFACE

Founding is one of the most ancient methods of metal shaping.

Foundry practice includes such basic production processes as melting of metal, manufacture of molds, pouring of the metal into molds, solidification, shakeout and fettling of the castings.

The principle of casting consists in the following. The metal of the required chemical composition and quality is poured into a casting mold whose cavity conforms to the shape of the desired casting. As metal cools and solidifies in the mold, a casting results. During its crystallization and cooling in the casting mold, the metal acquires certain mechanical properties and service characteristics. The cooled and solidified casting is removed from the mold, cleaned, and subjected to further treatment if necessary. There are a great variety of casting processes which can produce castings of any shape, size, and mass, for example, from several grams to a few hundred tons.

Castings are made from irons and steels and from nonferrous alloys such as copper, aluminum, magnesium, zinc, and other types. The castings from metals and alloys find wide use as parts of machines and instruments turned out by the machine-building and instrument-making industries. What makes the foundry practice most popular is the possibility of producing cast parts of complex shapes with minimum machining allowances and good mechanical and service properties. Mechanized and automatized casting processes help decrease the cost of castings.

The basic molding process is sand-mold casting which accounts for 80% of the total output of cast products.

But the dimensional accuracy and surface finish of sand-mold castings do not satisfy in many cases the requirements of modern machine-building and instrument-making industries. That is why special casting processes find an ever increasing application. These are permanent-mold casting, die casting, investment casting, shell casting, centrifugal casting, and other precision processes which

produce cast components of increased dimensional accuracy and low surface roughness with minimum-finish allowances.

The book is based on the lectures read to the students of machine-building secondary schools and also on the foundry practice course included in the curriculum of the Bauman Higher Technical School of Moscow.

The book opens with a detailed description of sand molding technology, melting, pouring, and fettling of castings from gray iron which is one of the most widely used casting alloys. Subsequent chapters treat the methods of fabrication of castings from malleable iron, steels, and alloys of copper, aluminum, and magnesium. One part of the book places a particular emphasis on the theory of casting. The last part which includes several chapters contains basic information on special casting processes such as permanent mold casting, die casting, investment casting, and shell casting. The authors have paid special attention to the sequential presentation of various aspects of founding in a clear and readable language.

Each chapter first describes the essence of production processes, the influence of operating conditions on the quality of castings, and then presents the rational fields of application of the production methods. In the authors' opinion, such a presentation of the material helps the reader to acquire more readily the basic knowledge of foundry practice.

The authors wish to thank professor G. F. Balandin, D. Sc. (Tech.), head of the chair of foundry practice of the Bauman Higher Technical School, for his valuable recommendations as regards the content and the methods of presentation of some chapters, and engineer P.S. Ivanov who has made many improvements when translating the book.

Part I

MOLDING TECHNOLOGY

Chapter 1. CASTING MOLD. GENERAL

A casting is produced when molten metal is poured into a *casting mold* and left to cool and solidify. Consider the sequence of steps involved in molding a casting of simple shape, for example, an iron bushing 1 (Fig. 1). First, it is necessary to make a wood pattern 3 using the part drawing.

The *pattern* is a form bedded down in sand to make an imprint in the mold conformable to the shape of the desired casting. Since the melt that fills the mold contracts as it cools and solidifies, the pattern maker must take into account the *shrinkage* of metal. He must also consider a *finishing allowance* for subsequent machining of certain portions of the casting. So, to produce a casting of the required shape, the pattern should be slightly larger in all dimensions than the finished piece to allow for metal shrinkage and the stock left for machining. Patterns are made of wood, metal, gypsum, plastics, and other materials.

The pattern shown in the figure is a split piece that consists of two halves mutually centered and locked in place with tenons and mortises.

The core 9, which is part of the mold, serves to form the central hole of bushing 1. The core is prepared from *core sand* compacted in a core box 2 into the shape of the resultant cavity. The shape is then baked dry to give it strength. In the assembled mold the core is held in its correct position by impressions—known as *core prints* (*core print seats*) 4 on the original pattern 3. The core is thus made longer than the casting cavity by the size of prints.

The mold for the bushing is made up of two mold halves, the upper 6, called the *cope*, and the lower 14, known as the *drag*. They are prepared from *molding sand* rammed in metallic box-like frames, called *flasks*, or *boxes*. A molding box which holds the top half or cope of the mold is called the *cope*, and that which holds the bottom half or drag of the mold is termed the *drag*.

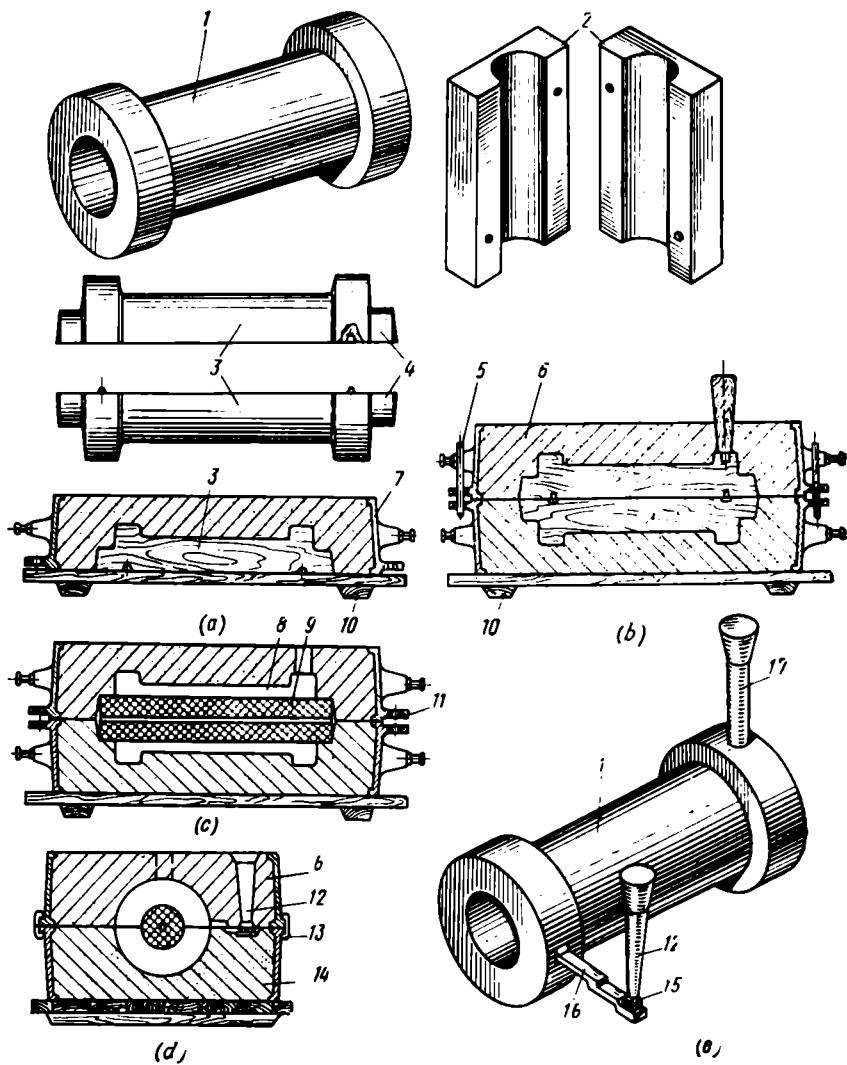


Fig. 1. Sequence of steps in molding an iron bushing

Production of the mold for the bushing. To form the desired imprint in the mold drag, one half-pattern 3 is placed on a *molding board* 10 along with a flask drag 7 (drag box) as shown in Fig. 1a. The surface of the half-pattern and board is now dusted with dry facing sand or sprinkled with a parting liquid (kerosene), and the flask drag is

filled up with ordinary molding sand, which is rammed to consolidate it. Any excess of the molding sand is cut off level with the upper edges of the drag and then the drag is turned over and placed on the molding board 10. The upper half of the pattern is now fitted on its lower half and the flask cope is placed on top of the drag (Fig. 1b). Next, facing sand is sprinkled over the surface of the pattern, the sprue and riser pins are set up, and then molding sand is riddled into the flask cope and rammed over the entire surface.

The cope half of the flask is now lifted off and set aside, the pattern is rapped and withdrawn, the core is put in position, and then the mold is closed by placing the cope on top of the drag (Fig. 1c), location being effected by pins 5 and holes 11 in the lugs of the flask. The molten metal filling the cavity exerts pressure on the mold walls and tends to lift the cope, with the result that a gap may form at the parting plane, through which the melt can run out from the mold. To preclude leakage of the metal, the cope is fastened to the drag with clamps 13 (Fig. 1d) or sometimes weighted.

In pouring molten metal into the mold, the metal enters the mold cavity 8 through a system of channels, called *gating*. Fig. 1 shows the gating system that consists of a sprue 12, slag trap 15, and ingate 16 to admit the molten metal to the mold cavity. The gating system also includes a flowoff 17 (Fig. 1e) whose principal function is to allow the air and gases evolved during pouring to escape from the mold and reveal the level of metal in the mold.

After the metal has solidified and cooled, it is necessary to shake out the casting and thus destroy the mold, knock out the core, cut off the gating, and clean the casting of the molding sand.

The described casting mold is *dispensable*. Such molds are made of *molding sands*, the basic constituent of which is quartz sand. Clay is used as a bonding substance which imparts strength to the sands. Since the strength of such molding sands is relatively low, while the pressure of molten metal on the mold walls is rather high, sand molds must be made *thick-walled*. The use of binders which give high strength to the molding sand enables the production of *shell-type* (thin-walled) molds. This also effects a drastic cut in the consumption of sand and, besides, ensures closer dimensional tolerances and better surface finish of castings owing to the specific properties of the molding sand.

Thick-walled sand molds allow for molding intricately shaped castings of a few grams to tens of tons in mass from various alloys in piece, batch, or quantity production. The production process is relatively simple, makes use of cheap materials, provides for adequate accuracy and tolerable surface roughness of castings, and is adaptable to mechanization and automatization.

Foundries also use molds prepared from high-refractory materials, based on graphite, for example. These molds are called *semipermanent*.

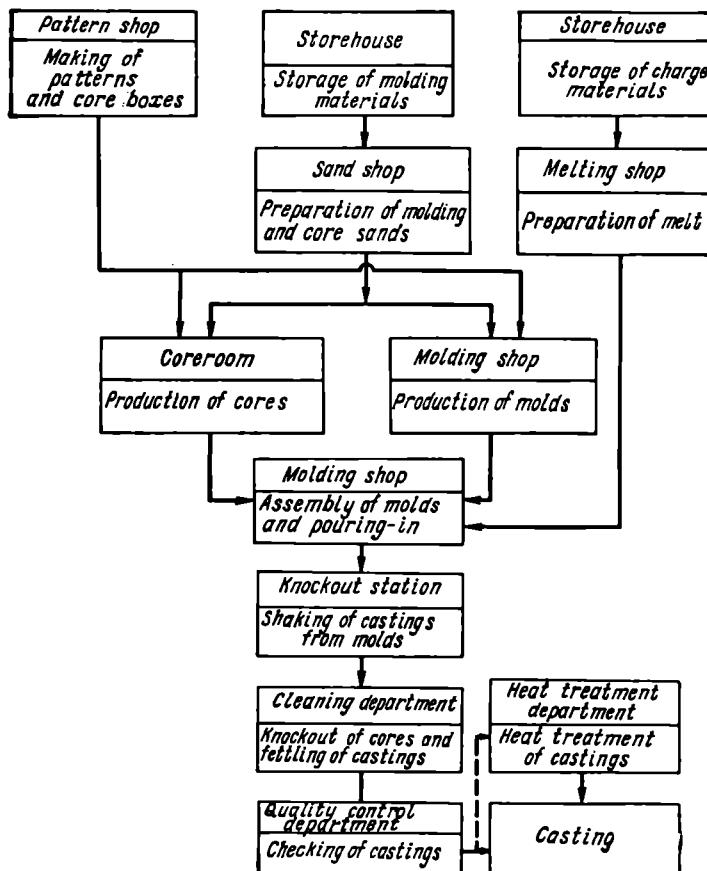


Fig. 2. Flow-chart showing the sequence of operations involved in the production of a casting in a sand mold

ment. A mold of this type is capable of producing a few tens of castings without showing substantial wear. They are applicable for casting small lots of pieces from cast iron and nonferrous alloys (aluminum, magnesium, and copper types). Semipermanent molds, however, are not durable enough for use in the mass production of castings, while the high cost of these molds prohibits their application in piece production.

Permanent metal molds find wide uses in the foundry practice. These molds are adaptable to the production of tens and thousands of castings from steel, cast iron, and nonferrous alloys. The permanent mold process can produce castings of intricate shape, which

may range up to several tons in mass. Generally, this process is practical for making parts of small or medium mass (a few tens of kilograms) from light nonferrous alloys.

The castings produced in permanent molds have smooth surface and increased accuracy of dimensions. Permanent mold casting excludes the use of molding sands, improves the conditions of labor, and is adaptable to mechanized and automated processes. A rather high cost of metal molds, however, limits their uses only to large-scale and quantity production.

An outline of the sand-casting process. Casting in sand molds is the most widespread technique employed in the ordinary foundry. The production process includes a variety of procedures carried out in special *shops* or *departments* of the *foundry* (Fig. 2).

The sand-casting process begins with the manufacture of a suitable *molding equipment* which comprises patterns or pattern plates, core boxes, flasks, sand drying plates, gages to check molds and cores for dimensional accuracy, and jigs and templates to verify the location of cores in the molds.

The production of *pattern sets*, which include patterns, pattern plates, and core boxes, rests with the *pattern shop* of the foundry. A very important procedure in the technological sequence of operations is the preparation of *molding materials* for the production of expendable and semipermanent molds. These are sands, binders, and special additives. The starting molding materials are held in bins and bunkers. The materials shipped to the foundry storehouse are as a rule inspected for quality and tested in the foundry laboratory to see that they comply with the certificate.

The molding materials are delivered to the *sand shop* which prepares molding and core sands, or mixtures, according to specifications. The sands are then transported to the *molding* and *core* shops of the foundry.

The process of production of casting molds is called *molding*. Hand, machine, and automatic molding find use in the foundry. Hand molding pays off in the piece, short-run production; the machine and automatic molding processes are profitable in the batch, high-run, and mass production of castings.

Cores are made in core boxes or with the aid of templates. The compacted cores are baked in special ovens (driers) to impart the required strength, increase gas permeability and decrease gas evolution capacity. Before being set in the mold, the cores are coated with washes, which consist of refractory materials such as graphite, powdered quartz (silica flour), and iron-free zirconium. Washes exclude burn-on, that is, sand sticking to the surface of castings, and metal penetration. For the same purpose, green-sand molds are dusted with facing materials such as graphite, talc, and charcoal, or coated with washes. In dry-sand molding, the cavities of molds are

washed and baked dry. The cores are then placed in position, the molds closed, locked with bolts or clamps, and made ready for pouring.

The starting materials for producing an iron or steel melt are foundry and conversion pig, cast-iron and steel scrap, chips, ferro-alloys, and nonmetallic materials such as fuels and fluxes. These charging materials are kept in the *charge store*, where they are prepared for melting—graded, ground to size, and blended to make up the charge of the prescribed chemical composition from the appropriately proportioned ingredients. Special conveyors then deliver the ready charge to the *melting shop* to obtain liquid metal (*melt*).

Various *melting furnaces* are available to melt and overheat ferrous and nonferrous metals and alloys. Shaft-type furnaces, called cupolas, provide for molten cast iron; electric and open-hearth furnaces, for steel; and flame furnaces, for cast iron and nonferrous alloys.

The melt must be overheated in the furnace to a certain temperature to have the required fluidity for proper filling of the mold. After its melting and overheating, the metal is poured into ladles for transportation to the pouring shop. As the metal fills the mold, it gives up heat to the mold walls and thus cools and solidifies.

After cooling, the mold is broken open, and the casting is shaken out of the mold. The *knockout operation* need be done only after the casting has cooled down to a certain temperature and has become solid enough, otherwise it may warp during shaking. The *shakeout station* of the foundry is equipped with special machines for shaking out the molds.

As-cast pieces have gates, risers, burrs, fins, burnt-on sand on the surface. In the *cleaning*, or *fettling*, department the gates, risers, and fins are cut off or chipped by special tools, and the surface of castings is cleaned in pneumatic and airless shotblast machines, in hydroblast, sandblast, hydro-sandblast, and tumbling barrels.

The castings are then inspected for acceptance at the *quality control department*. The inspector makes check on the size and pressure-tightness of castings, presence of internal and external defects (shrinkage, blowholes, cracks), and on the mechanical properties and structure of metal. Minor flaws are corrected by electric-arc and gas welding, by impregnating with various resins and coating with cements.

To obtain the required structure and mechanical properties of castings and to relieve internal stresses, the cast pieces are often subjected to *heat treatment*—heating and cooling in ovens strictly to the prescribed schedule (the time and temperature of treatment). This operation is carried out in the *heat-treatment department* of the foundry. This done, the castings are cleaned again and checked for quality.

The sound castings are kept at the store, from where they are taken

for machining. Some castings are painted before storing to protect them against corrosion.

Machining gives the casting its final geometric shape, desired dimensional accuracy and surface finish in compliance with the drawing and specification on the ready part. Machine treatment is the most labor-consuming process in machine building. It accounts for 40 to 60% of all the efforts spent on making a machine. Obviously, it is desirable to produce a casting with the least stock left for machining or make it to so close tolerances and its surface so smooth as to exclude machining altogether.

Chapter 2. BASICS OF PATTERN DESIGN AND MAKING

2.1 GENERAL

For molding castings, the foundry uses a large variety of devices and appliances which make up the *casting equipment*. The proportion of equipment which includes all appliances required to form an imprint in the mold of the shape of the desired casting constitutes a *pattern set*.

The pattern set comprises the patterns of the casting and gating elements, core boxes, pattern plates for mounting and fixing in position the patterns of the casting and the gating system, sand drying boards, jigs and templates for finishing up the molds and cores to size.

The molding process makes use of flasks and various accessories, such as filling frames, plates, pins, clamps, and templates, along with the pattern set, which form the *molding equipment*, that is, a complete outfit of devices called upon to produce a sand mold and make it ready for pouring.

Pattern making is a responsible kind of job and needs workers of high skill.

The pattern set must satisfy the following requirements: secure the desired shape and size of the casting; have high strength and long life in order to make as many molds and cores as required; be simple in design for ease of manufacture, light in mass and convenient to handle, cheap and readily repairable; retain its dimensions and rigidity during the definite service period.

The required accuracy, strength, and life of a pattern set depend on the production quota involved. In the piece and short-run production, wood patterns find most extensive application; in the large-scale and mass production, metal patterns are preferable since they are more durable than wood counterparts, though costlier; in batch production, use is often made of patterns manufactured from plastics, for example, epoxy resins, and also from gypsum, and cement.

2.2. WOOD PATTERNS

2.2.1. PROPERTIES OF WOOD

Wood used as a pattern-making material shows a number of favorable properties—it has low density, good workability, lends itself to gluing, holds well varnishes and paints, and is comparatively cheap. But wood is inherently nonuniform in structure, absorbs and

gives off moisture, so that it varies in volume, warps and thus changes its mechanical properties. These drawbacks can be remedied to a certain extent by choosing the appropriate species of wood, the right schedule of drying and treatment during the making of patterns.

Species of wood used in pattern making. The choice of the kinds of wood, soft or hard, depends on what purpose and how long the pattern must serve.

Lime is a soft wood, readily machinable, has low strength, high hygroscopicity, and increased shrinkage on drying. It is used for small and medium-size patterns.

Alder is a comparatively soft wood, easily machinable, features small shrinkage and warpage. It goes for the production of master patterns (patterns for casting metal patterns), small and medium-size patterns, core boxes, and also thin-walled patterns with strengthening ribs.

Pine is a well machinable wood, has low shrinkage and insignificant warpage. Its uses include the manufacture of medium- and large-size patterns of any configuration, core boxes, templates, and so on.

Spruce machines with difficulty and warps heavily. The surface of patterns after machining is yet rough, particularly at end faces. It is suitable for large and inessential patterns and core boxes.

Birch machines easily on the lathe, heavily warps and shrinks, is rather hygroscopic and readily decays. It gives a very smooth surface after polishing. This wood is used for small pattern parts of a circular shape (as core prints, bosses), and, sometimes, for facing medium-size and large patterns.

Maple is very hard and difficult to machine, shrinks and warps insignificantly. After planing, the surface of patterns becomes clean and smooth. The wood makes a good material for small important patterns when casting parts in lots and piecemeal, and also for lining of essential portions of large and medium-size patterns and for master patterns.

Oak is a very hard wood and is difficult to machine. The uses embrace the production of pattern-maker and molder tools.

Plywood of birch, alder, or first-grade beech woods machines well, warps little, has a clean and smooth surface. It is utilized for flat thin-walled patterns, pattern plates, frames, and other parts.

Lumber comes in planks, bars, beams, and so on. By the Soviet standards, the plank is a sawn timber whose width is more than twice its thickness; the bar has a width that does not exceed its twofold thickness; and the beam is a squared timber over 100 mm thick.

2.2.2. WOOD DRYING

Wood patterns and core boxes are made of dry wood to exclude warpage. Besides, the working surfaces of patterns are given the coats of nitrocellulose enamels and varnishes.

The woods that go for patterns must have no knots as they affect the machinability and mechanical properties of patterns. One must also discard the rot, cracked, and cross-grained woods which impair the surface quality, increase the amount of rejected patterns and intensify warpage.

Lumber (planks or bars) is first seasoned in the air and then dried in special ovens (kilns).

Wood *seasoning*, or *weathering*, occurs owing to natural circulation of the surrounding air that washes over the surface of lumber and takes away moisture. For this, lumber is laid in stacks on wooden or concrete supports under the shelter and is left for seasoning, which takes up to two years for soft woods and over four years for hard woods.

Natural drying does not need any special equipment, but the process lasts too long and the material may start decaying under unfavorable conditions.

Kiln drying by hot air is the most popular process. It shortens the drying period, enables control over the moisture content of wood and thus its quality. The shortcoming of kiln drying is that it involves considerable expenditures on equipment and consumption of a large volume of steam. The period of curing depends on the kind of wood, its thickness and moisture content. To prevent its warpage in drying, lumber is preliminarily treated by damp steam supplied to the drying chamber. The steaming procedure is carried out up to three times. Soft woods are dried at 40 to 75°C and hard woods at 35 to 55°C.

To guard against changes in the structure of surface layers of wood, which increase the hardness and impair the workability of wood, the temperature of drying must not exceed 80°C.

The process of drying in chamber kilns takes 5 to 8 days for soft woods and 8 to 16 days for hard woods.

The moisture content of wood used for patterns must not be over 8-12%. Wood shrinks in drying rather nonuniformly: 0.1 to 0.3% along the grain, 3 to 8% across the grain, and 5 to 12% in the direction tangent to the annual rings.

2.2.3. EQUIPMENT AND TOOLS

Various machines are available for treatment of woods. These are circular and band saws, planers, panel planers, millers, grinders, and tenoners.

The circular saw bench (Fig. 3) can saw planks and bars both lengthwise and across; the band saw is used for rectilinear and curvili-

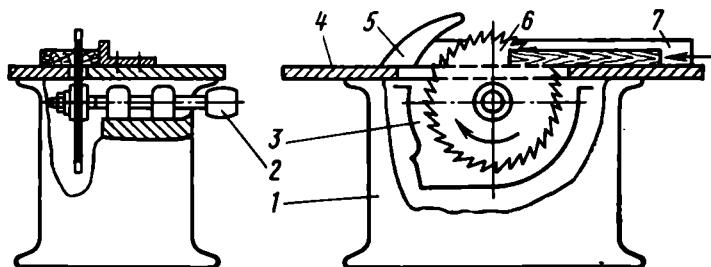


Fig. 3. Circular saw bench
1 — bed; 2 — belt pulley; 3 — protective casing with a sawdust exhauster; 4 — table;
5 — guide knife; 6 — circular saw blade; 7 — guide bar

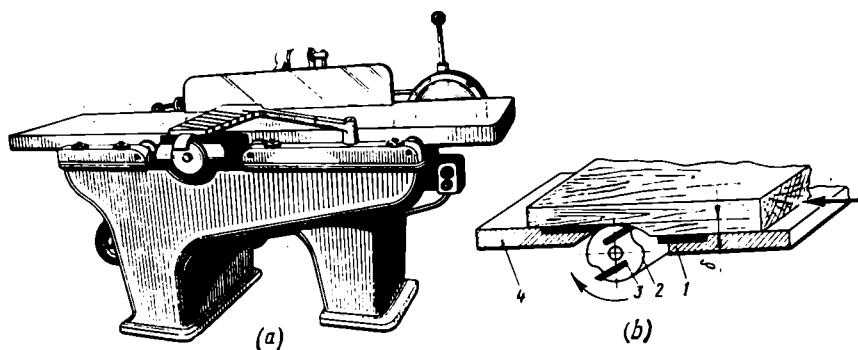


Fig. 4. Planer (a) and its cutter block (b)
1 and 4 — front and rear plates; 2 — cutter drum; 3 — cutters

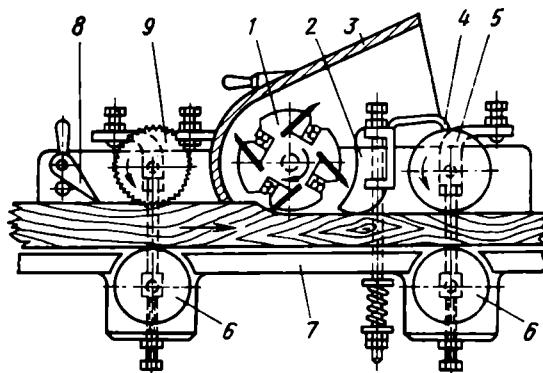


Fig. 5. Panel planer
1 — cutter drum; 2 — bolder; 3 — cast iron hood for the removal of shavings; 4 — lip deflector; 5 — rear feed roller (smooth); 6 — lower rollers; 7 — table plate; 8 — brake pins; 9 — front feed roller (serrated)

near sawing of planks. Lumber is fed by hand to the cutting edge of the moving circular saw blade. For safety, the saw is guarded, along with pulleys, by an appropriate screen.

The planing machine (Fig. 4a) serves for planing bars and planks. The main block is an electric motor-driven cutter drum located on the table. By shifting the table plate with the aid of screws, the operator adjusts the thickness δ of shavings cut off the plank (Fig. 4b), which is fed manually by pressing it to the plate.

The panel planing machine smoothes out the surface of a plank to make it even in thickness. The machine is commonly used to plane the planks one surface of which has been worked on the planer. The panel planer has a table, movable vertically to adjust it for cutting off the plank to the desired thickness (Fig. 5), and a cutter drum 1 driven by an electric motor. The plank is fed to the drum by knurl rollers.

The milling machine works out the curved surfaces of wood pieces, mostly used for core boxes which have a large number of such surfaces. Vertical, horizontal, and profiling millers are available.

The grinding machine polishes the workpieces of patterns and core boxes with abrasive sheet. The machines come in band-grinding, disk-grinding, and combined types.

The lathe turns the workpieces of patterns and core boxes that have the shape of solids of revolution. The piece can be fixed in the

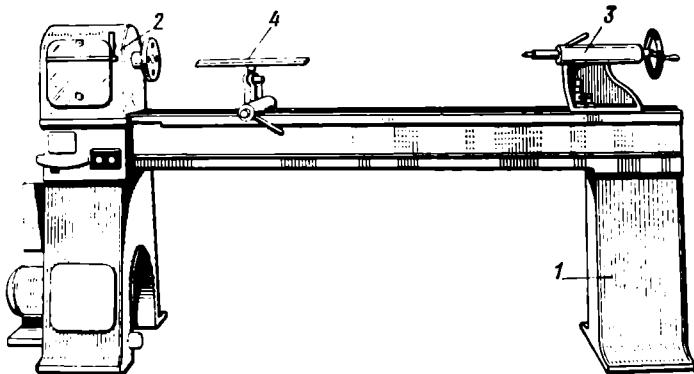


Fig. 6. Lathe

lathe centers, on the faceplate, or in a special chuck. The pieces of 150 to 300 mm in diameter with the grain running normal to the axis of rotation are fastened to the faceplate with screws. The pieces of patterns for casting sheaves, flywheels, and other parts 3000 mm or more across are turned on faceplate lathes. Fig. 6 shows the lathe whose bed 1 mounts a headstock 2, tailstock 3, and a handslide rest 4 or a carriage to enable mechanical feed of the cutter. The pattern

maker uses various electrically driven tools to plane and mill wood pieces, drill holes, polish surfaces, drive in studs and screws. The most common tools are a circular trimming and slitting saw, band saw, plane, cutter, reamer, and grinding and polishing tools.

Measuring instruments. In making patterns and core boxes the pattern maker uses a shrinkage rule, square, bevel, marking gage, dividers, outside caliper, inside caliper, and slide caliper (Fig. 7).

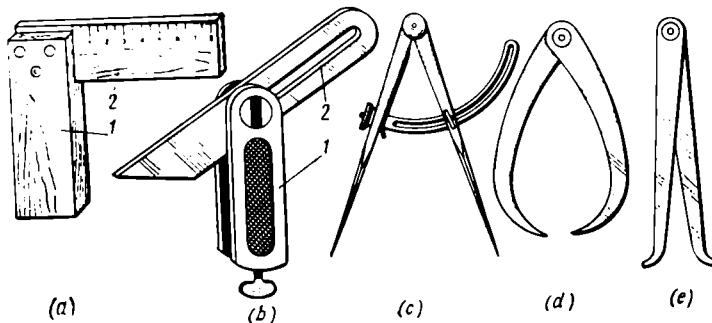


Fig. 7. Measuring instruments

(a) square; (b) bevel; (c) dividers; (d) outside caliper; (e) inside caliper; 1 — arm; 2 — rule

The *shrinkage rule* serves to measure out the workpieces of patterns and core boxes. It is made longer than a standard meter rule bearing similar gradations to allow for shrinkage of metal. Shrinkage allowances range from 1, 1.25, 1.75, to 2% or more, depending on the alloy cast.

The *square* is intended to check right angles and lay out lines normal to each other on bars and planks. It consists of an arm, or support, and a thin rule fastened at a right angle to it. In using the square, the pattern maker places the support on the piece surface taken as a locating plane.

The *bevel* is a metal or wooden rule intended to check various angles and mark out wood pieces. It consists of a prop and a rule pivoted on a bolt.

The *marking gage* is used for drawing parallel lines on planks. The scribing block carries two wooden or metal bars with metal studs at the end. In tracing the lines, the pattern maker presses the block to the locating surface of the plank and fixes each bar with its metal stud at a certain distance from the block surface. As he forces the block to slide, the stud scratches the line on the plank surface.

The *outside caliper* is used to measure outside dimensions of circular shapes and the thickness of pieces. The *inside caliper* measures hole diameters, recesses, and distances between the individual parts of a pattern.

The *slide gage* is intended to mark off large circles. Cutting and planing tools. The pattern maker uses a number of cutting and planing tools (Fig. 8) such as chisels, common planes,

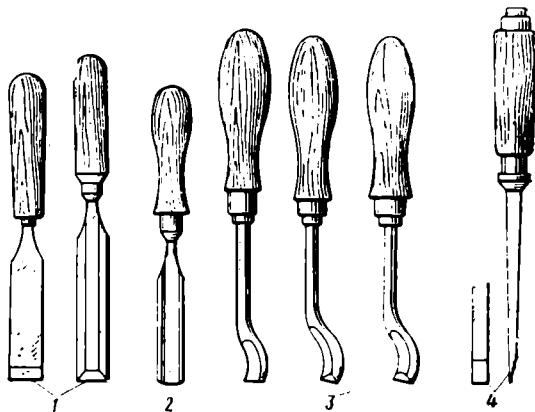


Fig. 8. Cutting tools

1 — side chisel; 2 — round-nose chisel; 3 — profile chisels; 4 — ripping chisel

jack planes, smoothing planes, tooth planes, and also drills and appliances for jointing parts.

Side chisels cut flat and arched surfaces. *Round-nose chisels* shape internal curved surfaces. *Profile chisels* come handy where it is im-

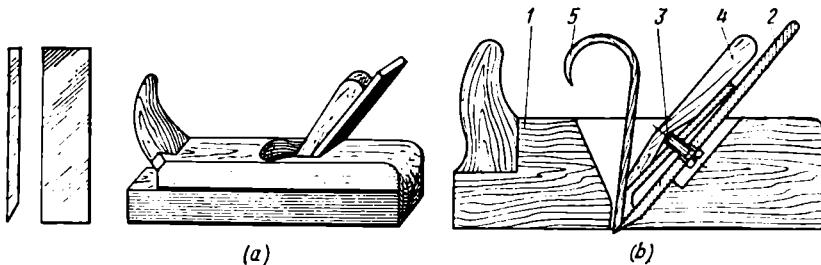


Fig. 9. Single-iron (a) and double-iron (b) planes

1 — block; 2 — cutter; 3 — curved plane; 4 — wedge; 5 — shaving

possible to finish surfaces with common chisels. *Ripping chisels* cut out depressions in patterns and core boxes.

The *jack plane* is only suitable for rough planing of lumber. The tool has a block with a slit to receive a round-nose blade cutter fixed at 45° with a wedge.

Single-iron and double-iron planes (Fig. 9) give a better surface finish. Double-iron planes are applicable for working side and sectional surfaces of wood pieces.

The smoothing plane works flat surfaces over 300 mm in length. It is similar to a common plane in design.

2.2.4. CLASSIFICATION OF WOOD PATTERNS

Wood patterns are classified according to the type of alloy to be cast, method of molding, design, structural strength, complexity, and accuracy of manufacture.

By *design*, patterns can be split, unsplit, hollow, and solid. Small patterns are made solid, and large patterns hollow to lighten the piece, to save the material and reduce the cost of the finished pieces.

The design of a pattern depends on the *process of molding*. The patterns used in machine molding must have a flat surface of joint and the least number of detachable (or loose) parts. In this case, holes and cavities in the casting are shaped with the aid of cores. The patterns designed for hand molding can have detachable parts and curvilinear parting surfaces. The patterns intended for machine molding are applicable for hand molding, but the patterns used in hand molding are not always adaptable to mechanized processes.

By the *complexity of construction*, patterns are grouped into simple, relatively simple, complex, and very complex. Simple patterns are small unsplit or flat-split pieces without detachable parts. Relatively simple patterns have curvilinear surfaces, which shape mold cavities for casting pieces with a small number of cores. The patterns of intricate and very intricate shape are large pieces with curvilinear surfaces, which are used for molding thin-walled castings with a large number of cores.

By *strength*, wood patterns and boxes are divided into three classes (see Fig. 12).

Class 1 patterns and core boxes are pieces of increased accuracy for casting important parts. The patterns are applicable for batch production. They are made of beech, maple, oak and other hard woods. Thin parts of patterns are cast from aluminum. The detachable parts of patterns designed for hand molding are locked in place by metallic tenons of the dovetail type. The surfaces of patterns are thoroughly polished and then coated with pattern varnish not less than three times.

Class 2 patterns are intended for molding batches of parts or individual pieces of intricate shape. The patterns are of pine, lime and other species of the first and second grades. Core boxes are made split. Thin-walled patterns are mounted on pattern plates. The surfaces are polished to give a smooth finish and then varnished two times.

Class 3 patterns are designed for hand molding of individual castings and also for skeleton-pattern and template molding. The materials used are spruce, pine, lime and other kinds of wood. Detachable parts are glued or fastened with nails.

The patterns of the first, second, and third classes of strength are serviceable for at least 150, 30, and 8 molds, respectively.

By the *accuracy of making*, wood patterns are divided into three classes.

The degree of accuracy depends on the amount of deviation of pattern dimensions from the values given in the drawing. The deviations can spread above and below the set values, respectively called upper and lower deviations. It is more difficult to make wood patterns to close and stable tolerances than metal counterparts, because wood readily absorbs moisture, swells, and just as readily dries up. The accuracy of a wood pattern is associated with its design and strength. A stronger pattern retains better its shape and size. That is why the patterns of, say, the first class of accuracy must be made to the first class of strength, and so on.

For the batch production of castings, it is necessary to have available two or three pattern sets (doublers) to enable the sequential use of pattern sets and repair of disabled patterns. These sets must be interchangeable: the core boxes of one set must be a good fit for the patterns of another set. Interchangeability is possible only if the pattern sets show size deviations which lie within the field of tolerances specified for the given class of accuracy.

2.2.5. DESIGN OF WOOD PATTERNS

By its design and size, the pattern differs from the casting it forms and from the finished product. The design of a mold and the process of its production determine the type of pattern, which can be a one-part, split, or multiple-part construction.

The pattern must have suitable extensions (core prints) in order to form in the mold imprints (core seats) for core prints of the core which hold it in its correct position in the mold. The core prints of the pattern conform in size and design to core prints of the core. To avoid damage to the mold cavity while removing the pattern from the mold, the sides of the pattern are made slightly tapered. This taper, or *draft*, is also provided in core boxes. Drafts can be of the design and mold types.

Design drafts are the drafts calculated at the design stage. Here, the dimensions of a casting correspond to the dimensions shown in the drawing.

Mold drafts are the drafts marked by the technologist-founder on the working drawing of the part if the design drafts are absent. Such

drafts change the drawing dimensions of the casting. The drafts on wood patterns usually amount to 1-3°.

The intersection of surfaces in castings must be smooth and form no sharp angles. *Filletting* eliminates internal corners of castings, and *rounding* does away with external corners. Fillets facilitate the removal of a pattern from the mold, prevent the formation of cracks and shrink holes in the casting. The radius of a fillet r should be taken to equal one-fifth to one-third the arithmetic mean of the thickness of the two walls that form the angle in the pattern. For example, if the thickness a of one wall is 24 mm and the thickness b of the other is 18 mm, then

$$r = \frac{a+b}{2} \cdot \frac{1}{3} = \frac{24+18}{2} \cdot \frac{1}{3} = 7 \text{ mm}$$

Patterns made to the first class of strength have fillets carved in their body. For patterns of class 2 strength, fillets are made of concave pieces glued at junctions. For patterns of class 3 strength, sharp corners are filleted with putty. In large patterns, it is permissible to form fillets over 15 mm radius by using wooden inserts set up at a distance of 800 to 1000 mm one from the other.

As metal cools and solidifies in the mold, it shrinks, or contracts, and the casting decreases in volume. A change in the linear dimensions of the casting due to metal contraction is called *linear shrinkage*. To produce a casting of the desired size, its pattern must be larger than the casting by the *shrinkage allowance*. Shrinkage of castings depends on many factors: the chemical composition of the alloy cast, conditions of melting, design of the casting and its shape, properties of molding sand, and other influences. In calculating and specifying the dimensions of a pattern, the pattern maker considers the linear shrinkages of the alloys cast, which are given in the appropriate tables compiled on the basis of experimental and practical data (see page 201).

The dimensions of a casting correspond to the drawing dimensions if the pattern maker properly allows for the shrinkage of metal when he makes the pattern. For this, the pattern maker uses shrinkage rules which are longer than a standard rule by the shrinkage value for the appropriate metal.

Along with shrinkage allowances, the pattern maker must take into account the *allowance for machining* the surfaces of the casting. This is the *stock* of metal left on the casting for its subsequent removal during machining to bring the piece to the size and surface finish as specified in the drawing. A certain stock of metal must be allowed for on all the casting surfaces, which are necessary to machine. The amount of finishing allowance depends on the material of the casting, its size, the production process (mass, lot, or piece pro-

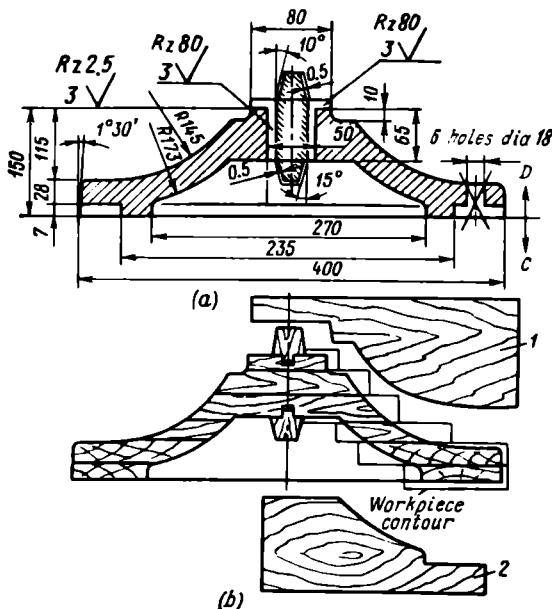


Fig. 10. Part drawing (a) with technological designations and pattern drawing (b)
 1, 2 — master sweeps

duction), method of molding, configuration of the casting, the position the wall surface occupies in the mold and during pouring.

The allowances made for machining are always taken larger in hand molding than in machine molding. The largest allowances are taken for the surfaces located in the cope half of the mold, since they are liable to contamination with slag. The amount of allowance is given in appropriate standards (see Tables 29 and 30).

Wood patterns and core boxes are made according to the part's working drawings, on which the technologist-founder indicates, as prescribed by the standard on the drawing of the casting, the drafts, surfaces to be machined and the amount of finishing allowance. He also outlines the pattern core prints, marks core-print dimensions, draws the cores and labels each by its number. Next, he indicates the drag and cope halves of the mold by arrows *D* and *C* drawn vertically from the parting line. The part drawing thus becomes a schedule (production) drawing of the casting.

Figure 10a furnishes an example of marking the technical data on the part drawing, which are necessary for the subsequent making of the pattern set. The pattern maker now draws out the pattern to the production drawing on a panel glued of wooden plates, or on a

plywood sheet, or sometimes on an aluminum plate with the aid of a sharp scribe (Fig. 10b).

Then, using the shrinkage rule, he draws on the pattern drawing the full-size casting and its section, tracing no dash lines, nor marking the dimensions. The pattern maker then marks out the pattern drawing. He indicates machining allowances, core prints of the core, mold tapers, and the position of the parting line between cope and drag. Next he determines the size of the workpiece from the pattern drawing, marks out and prepares templates, verifies the dimensions of patterns and core boxes during manufacture and when accepted by the quality inspector.

The pattern-maker draws out only those projections and sections which are necessary to determine the size of workpieces and the outline of templates. He can commonly do without special drawings of a pattern which would show its construction. Only in particular cases does the technologist-founder draw up the sketches of most intricate units of the pattern on the drawing of the casting, specifies the materials to be used and methods of jointing the workpieces. The pattern-maker himself designs the wood pattern, thinks over the technology of its manufacture, selects workpieces for parts of the pattern and contemplates the ways of jointing the parts. In doing this, he must strive to make the pattern of the desired rigidity, strength, and accuracy with the minimum of labor and materials consumed. This is possible to accomplish if the materials used, the design of pattern parts and method of their jointing comply with the required class of strength of the pattern being made.

Methods of jointing pattern workpieces. Patterns are generally made from separate wooden parts rather than from a single piece in order to give the finished products the desired strength and ability to resist warpage. The basic types of fastening the workpieces are building-up and mortising.

Building-up is jointing the pieces of timber both in width and thickness to make up shields and boards (Fig. 12).

Mortising is locking together planks and bars at an angle to each other by tenons and mortises. The accuracy and strength of the pattern largely depend on how the pattern maker has mortised individual pieces.

To facilitate the work of the pattern maker and improve the reliability and quality of products, the pattern shops use a variety of *standardized workpieces* and *units* of patterns. This also increases the efficiency of workers since the task of preparing and assembling individual units can be assigned to the less skilled labor and intricate jobs to high-skilled pattern makers.

Wooden workpieces (Fig. 11) used for various elements of a pattern set come in two types, rectangular and circular. The former are shields, boards, and boxes, and the latter are solid cylindrical and

annular parts, drum-type and trough-shaped elements. Pertinent standards specify the dimensions of workpieces supplied to pattern shops. This increases the reliability of ready products and effects savings.

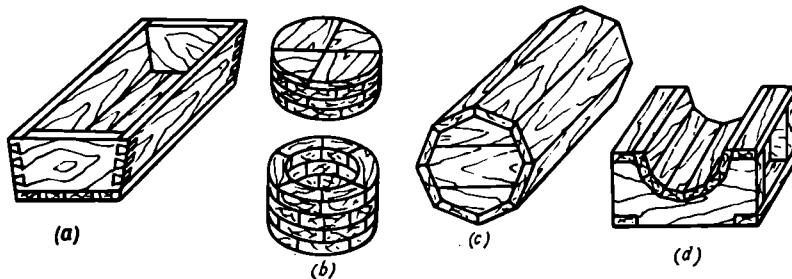


Fig. 11. Workpieces for various elements of a pattern set
(a) rectangular; (b) solid, cylindrical and annular; (c) drum-type; (d) trough-shaped

The design of pattern elements (Fig. 12) and the method of joining them depend on the class of strength and accuracy to which the pattern must be made. In preparing the patterns of the first

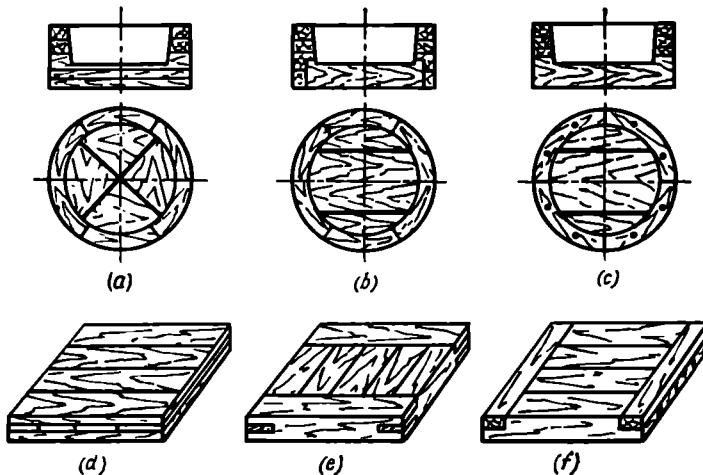


Fig. 12. Patterns made to three classes of strength
a) and (d) first class; (b) and (e) second class; (c) and (f) third class

class of strength, the cylindrical types are made up of segments in several stacks. The same method also works for building up flat elements of patterns. This gives high strength and rigidity to pat-

terns. For patterns of the second class of strength, the method of fastening is simpler. It is still more simple for patterns of class 3.

Fillets also differ in construction (Fig. 13). For straight unsplit corners in the patterns of the first and second classes of strength, fillets are made in the form of milled concave pieces glued in position (Fig. 13a and b). Sometimes fillets are milled directly in the body of a pattern (Fig. 13c). Where the radius of fillets can be less than 10 mm, it is allowed to fillet sharp angles in all classes of patterns by plaster or putty (Fig. 13d). Detachable parts 1 (Fig. 14) are fastened to patterns with dovetails, pegs, and pins. The first type of joint is most reliable.

The right location of half-patterns relative to one another greatly increases the accuracy of castings. Half-patterns are secured in position by wood dowels glued in holes in the upper piece, or by metal dowels (Fig. 15).

Patterns are provided with lifting arrangements for drawing them from the cope or drag. These are either lifting eyes used for large patterns or draw screws for small patterns (Fig. 16).

Core boxes (see Figs. 103 and 104) are made split or unsplit in design. The use of either type depends on the configuration of the core being molded and the class of strength and accuracy of the pattern set. Split core boxes are simpler to manufacture and cheaper. Unsplit (knockout, or turnout) core boxes have a rigid frame (see Fig. 106) with insertion pieces (loose sides or loose pieces) which form the working cavity for molding the core.

2.2.6. PRODUCTION OF A PATTERN SET

As an example, consider the production stages involved in making a pattern set for a tapered roll. According to the part drawing (Fig. 17a), the pattern of the roll should be solid, with the detachable upper sleeve because the parting plane of the mold will pass along the line I-I. The pattern must be made to the first class of strength, from birch or pine wood. To give more strength to the pattern, the roll rim (Fig. 17b) should be built up of wood pieces, or circular segments 1, arranged, for example, in three rows, one above the other, with six segments in each. The disk should consist of two rings 2 glued so that the grain of one ring can lie normal to the grain of the other ring.

First, the templates of segments 1 are placed on the board and outlined with the pencil to mark their contours. The board is then sawn out along the contours to obtain the workpieces of segments. The templates are prepared from cardboard or plywood, each to the size of the respective segment in every row. The allowance for turning is taken to be about 4 or 5 mm on each side of the piece.

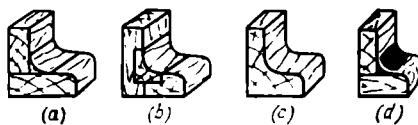
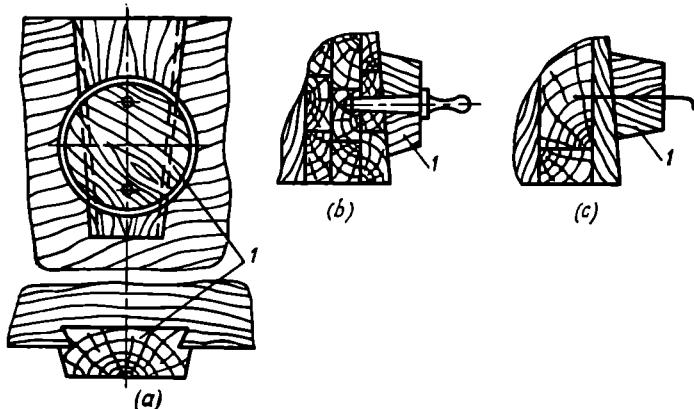
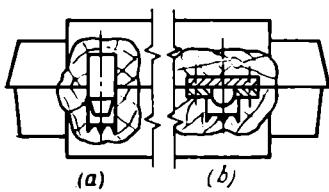
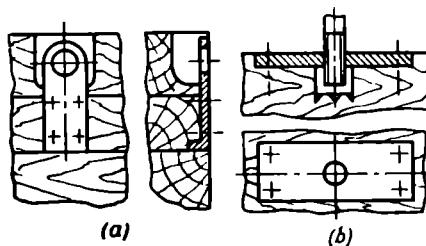


Fig. 13. Fillets

Fig. 14. Fasteners for detachable pattern parts
(a) dovetail; (b) peg; (c) pinFig. 15. Locating means for pattern halves
(a) wood dowel; (b) metal dowelFig. 16. Lifting arrangements for patterns
(a) lifting eye; (b) draw screw and threaded hole

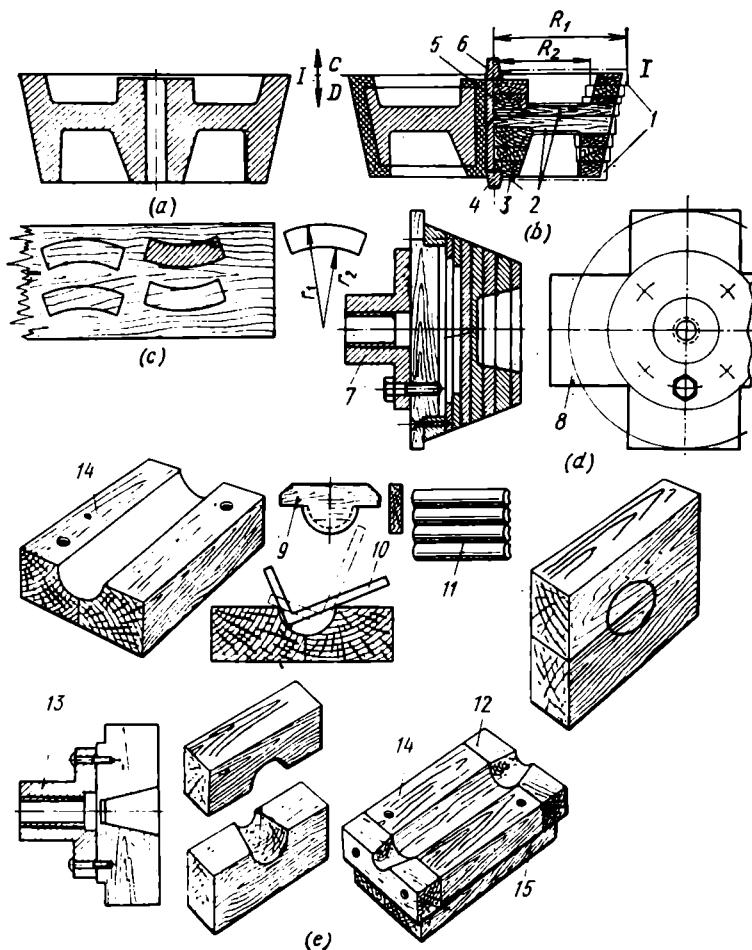


Fig. 17. Sequence of stages in making the pattern set for a tapered roll

The grain of wood in the segment should lie in the direction of the chord (Fig. 17c).

The ready pieces are now joined together with a glue to make up the workpiece of the roll, which is then turned on the lathe. The workpiece can be fastened on to a faceplate 7 or to a wooden cross-piece 8 by screws (Fig. 17d). Internal surfaces in the lower and upper parts of the pattern are machined with a cutter. Depressions in the disk are cut on both sides to fit in the sleeves with core prints. Next, sleeves 5 , 3 and core prints 6 , 4 intended to form core print seats in the mold are turned. The sleeve 3 is cemented to the pattern, and the sleeve 5 is made detachable for ease of molding. The core box

(Fig. 17e) is made up of symmetrical halves, that is, split along its axis. First, pairs of bars are coupled to form the middle portion 14 of the box and then the cylindrical cavity is carved by a round-nose chisel, using a template 9 and square 10. This cavity can also be obtained by milling.

The conical cavities for core prints are cut out on the lathe in two pieces 12. For this, the pieces are first bonded together with adhesive paper and rigidly fastened with steel combs 11.

Then the bonded pieces are screwed to the faceplate 13 to cut out the desired taper hole. This done, the workpiece is removed from the faceplate and its sides are planed to the required height of core prints. The workpiece is now ripped loose with a chisel along the plane of joint, the paper stripped off, each piece 12 glued to the middle portion 14 and fastened with screws. Finally, a wooden shield 15 is glued to each half of the box to make it more rigid.

The ready pattern set is sent for acceptance to the quality control department of the pattern shop, where it is checked against the part drawing and the pattern drawings used in manufacturing the patterns and core boxes. All the elements of patterns and core boxes, such as fillets, detachable parts, and fastening means are examined for quality. The stand-by patterns (doublers) and core boxes are also verified for interchangeability.

Painting of patterns. The accepted pattern set is sent to the painting room where the patterns and core boxes are painted to protect them against moisture, add strength and smoothness to the surface, and also decrease the adherence of molding and core sand.

The painting process includes the operations of priming, filling, double or triple varnish coating, and polishing with emery paper after each step of painting.

Priming smoothes out the irregularities left on the wood surface after planing. The paint is the mixture of drying oil and pigments.

Filling makes good minor faults on the pattern surface, such as dents, fissures, cleavages, and others. The composition of the filler includes 70% ground chalk, 15 to 20% size, and 10 to 15% drying oil. It is usual to paint the surfaces of patterns and core boxes in various colors as this simplifies the process of forming the casting mold (Table 1).

The painting room must lie isolated from the shop premises, have good balanced ventilation and fire-fighting means because paints and varnishes are harmful to the health and inflammable.

The painted pattern set is marked to specifications. For this, requisite figure and letter symbols are cut of thin brass sheet and fastened to the idle surfaces of pattern elements. The patterns, core boxes, and detachable parts which form the pattern set must have the common drawing number. Every pattern must also bear indications of how many core boxes and detachable parts it has.

Table 1
Coloration of Wood Pattern Surfaces

Surface of parts	Color
Not subject to machining	Red for iron, gray for steel, and yellow for nonferrous metal castings
Subject to machining	Black circles on the red, gray, and the yellow background
Core prints	Black
At junctions of patterns and detachable parts	Black fringe at the intersection of surfaces
Fastening parts for patterns and core boxes, the imprints of which in molds and cores have to be stopped off	Black stripes in the form of slant dashes on the red, yellow or colorless background
Risers, gating elements, and flow-offs (for taking test samples and specimens)	Black stripe along the contour of interlinked elements to separate the gating parts from the common background of pattern
Working edges of templates and pattern plates	The same as the common background of pattern set

After painting and marking, the pattern set is delivered to the foundry or to the pattern storeroom. Wood pattern sets should be kept in a dry aerated room at constant humidity and temperature. Small patterns and core boxes must be stored in sets on shelves or racks.

2.3. METAL PATTERNS

Metal patterns and core boxes find use in mass and multiple production of castings. Unlike wood patterns, metal counterparts are more durable and accurate in size, have a smooth surface and do not deform in storage. Metal patterns and core boxes are intended for machine molding, and therefore they are tailored to suit the design of molding and core-making machines.

The *basic elements* of a metal pattern set are a pattern plate and core boxes, and the *auxiliary elements* are drying plates, jigs for grinding and assembling cores, and so forth.

Pattern plates are made composite or unit-cast. In the first case, the pattern is a separate unit which is subsequently mounted on the plate; in the second case, the pattern and plate make up a whole.

The patterns of gates, slag traps, and other gating elements are usually fixed on the plates together with the patterns for castings in order to do away with handwork in molding.

Design of metal patterns. The initial document used in designing a metal pattern set is the production drawing of the casting. It makes the starting point for elaborating the drawings of pattern plates, patterns, core boxes, and other elements. The pattern maker recalculates the dimensions of the part to allow for shrinkage of the alloy and then lays off on the working drawings of patterns and core boxes the dimensions which include shrinkage allowances. The need for this operation arises from the fact that the parts of metal patterns require treatment on machine tools, and the use of the shrinkage rule in this case would complicate the work of the pattern maker. In evolving the drawings of pattern plates, patterns, core boxes, and assembly jigs, it is common practice to use specifications and standards which prescribe the design and size of elements of the molding equipment, the necessary materials, accuracy of manufacture, surface finish, and so on.

Materials. These are mainly aluminum alloys containing 4 to 6% Si and 1.5 to 3.5% Cu. Large patterns and core boxes whose protruding parts can be subjected to bending, are advisable to fabricate from an aluminum alloy with a content of copper from 8 to 12%. For small patterns, core boxes, and pattern plates, gray iron of various grades makes a suitable material. Iron patterns have high strength, machine well, but are heavy and prone to corrosion.

Metal patterns, core boxes, and pattern and drying plates should preferably be made thin-walled and reinforced with stiffening ribs. The wall thicknesses for patterns and core boxes are listed in Table 2.

The *thickness of strengthening ribs* is taken equal to 0.7 or 0.8 the thickness of walls of patterns and core boxes, and that of edges up to 1.25-1.3 the thickness of walls. For the core boxes used in core-blowing machines and the patterns intended for high pressure molding, the wall thickness should be increased by 30 to 35%. The distance between adjacent strengthening ribs must not exceed 300 mm. The taper of ribs and walls of patterns and core boxes must lie within 1° to 1° 30'. The dimensional accuracy and surface finish of metal patterns and core boxes must meet the requirements of pertinent standards.

Core prints of patterns can be made integral with or separate from

Table 2

Nominal Thickness of Walls of Metal Patterns and Core Boxes

Mean overall size, mm	Aluminum alloy		Iron		Mean overall size, mm	Aluminum alloy		Iron	
	Pat-tern	Core box	Pat-tern	Core box		Pat-tern	Core box	Pat-tern	Core box
To 250	8	8	6	6	631-1 000	12	15	10	12
251-400	9	10	7	8	1 001-1 600	15	—	—	—
401-630	10	12	8	10	1 601-2 000	18	—	—	—

the pattern body (Fig. 18a) if the core prints involve difficulties in machining the pattern. The core prints must be strictly sized to specifications.

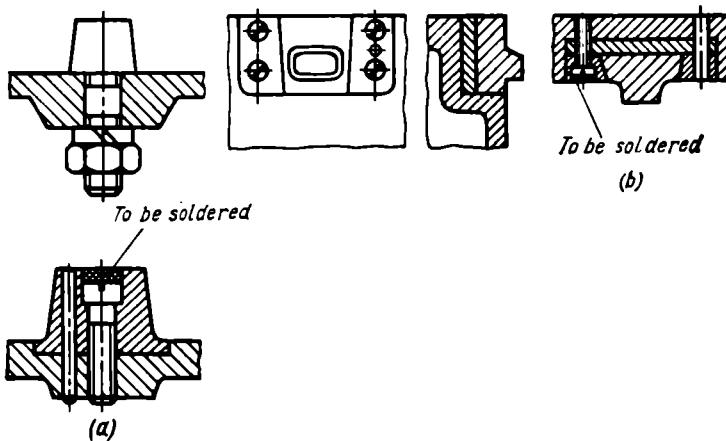


Fig. 18. Design of core-prints (a) and detachable parts (b) fastened to metal patterns

Detachable parts of patterns are fastened by means of a dovetail (Fig. 18b). The patterns of gating elements such as runners, skim gates, feed bobs (blind risers) are commonly made solid and fastened to the pattern plate with flat-head screws. Sprues and pouring cups are molded by using sprue patterns complete with a spring support cup as shown in Fig. 19a (the arrangement is called the spring gate stick). In the other arrangement illustrated in Fig. 19b, the sprue pattern is made fast to the pattern plate, and the hollow

cup pattern to the pressure plate. The first variant is largely applicable for making shallow molds.

Metal-pattern plates are applied in flask, flaskless, and shell molding. The design of a plate depends on the type of machine

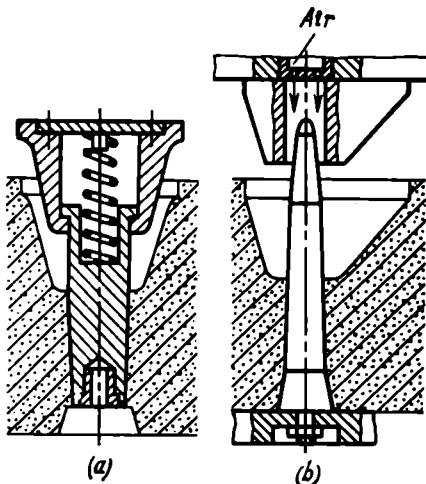


Fig. 19. Design of patterns for sprues and pouring cups

employed to form a half-mold, constructional features of castings, and the kind of mold. Most popular are single-sided pattern plates with patterns arranged on one side only.

Pattern plates for flask molding must have high rigidity and strength, which calls for use of appropriate grades of iron and steel.

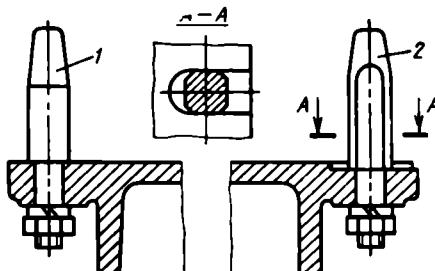


Fig. 20. Design of locating pins fitted into a pattern plate

Ribs provided on plates also make for the desired mechanical ruggedness (see Fig. 21). The pattern plates (Fig. 20) have centering (1) and guide (2) pins to ensure correct positions of the cope and drag.

Pattern plates for automatic molding (Fig. 21) must show enhanced rigidity and strength because the machines installed in the automatic molding lines pack molds at high pressure. To prevent molding sand from sticking to the surface of metal patterns and plates, these are equipped with an electric heating system. The temperature of

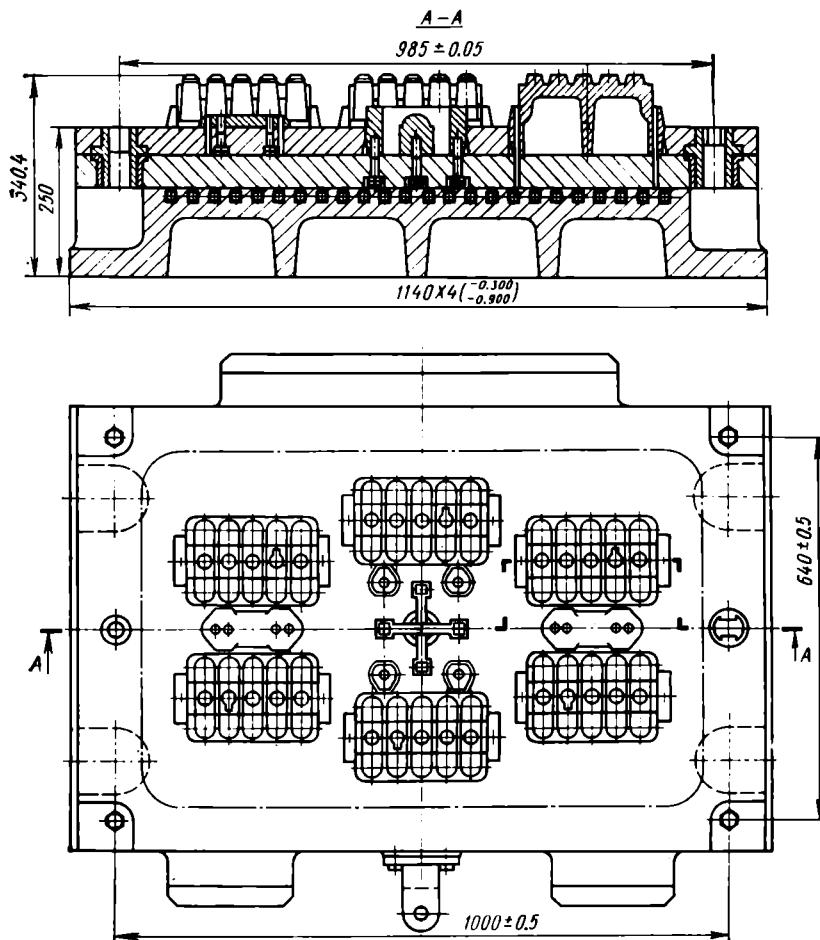


Fig. 21. Pattern plate for automatic molding

pattern plates must be 2 to 5°C above the temperature of molding sand, but not over 50°C. The system provides for automatic control of temperature. Such a system also finds widespread use in machine processes.

The *pattern set for automatic, flaskless, horizontal-stack molding* (Fig. 22) consists of a pattern plate 1 for pattern 2, heating plate 3 fitted with heating elements, and main plate 4 which is a part of the automatic molding machine. In replacing the patterns, it is enough to take off only the pattern plate. For mounting a pattern plate in the automatic machine, two locating holes and four faste-

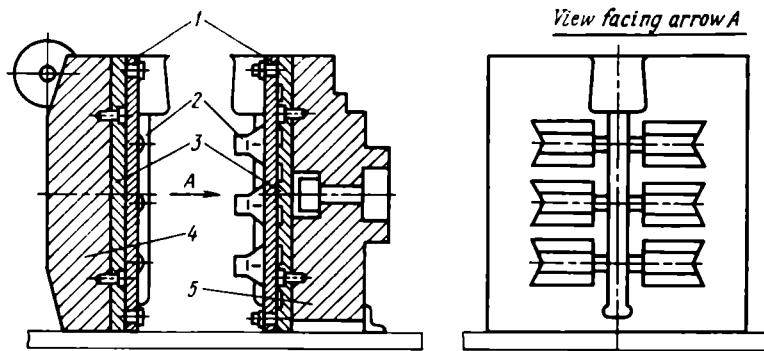


Fig. 22. Pattern plates for an automatic flaskless molding machine producing vertically split molds

ning holes need be drilled in the plate. For this a drill jig is placed on the plate and located from its side surfaces. Perpendicularity of side surfaces is verified by templates. The temperature of the template may vary from that of the plate only within $\pm 4^{\circ}\text{C}$. The misalignment between the axes of pressure plate 5 and counterpressure plate 4 must not be over 0.03 mm.

Production and assembly of metal patterns. The workpieces of metal patterns, core boxes and plates are cast in sand molds using wood patterns, called master patterns, that is, patterns for making metal patterns. Master patterns are made with due regard for mechanical or hand working of metal patterns. In determining the size of a master pattern, account is taken of the total shrinkage of the alloy of the pattern and the alloy of the casting. For example, if the pattern is to be made from an aluminum alloy with a shrinkage of 1.25% and the casting from a steel that shrinks 2%, then the master pattern should be made with consideration for the total shrinkage equal to 3.25%.

The workpieces of metal patterns and core boxes are machined on universal machine tools, such as screw-cutting, milling, planing, drilling, grinding, and gear-cutting machines. Shearing and sawing machines are used for cutting blanks.

The laying-out being over, the cast workpieces are machined according to the pattern drawing. To make a pattern more accurate in size, its contours, and certain sections are drawn to full-size scale on an aluminum sheet preliminarily coated with water colors or light varnishes. Individual projections of patterns are necessary for manufacturing metal templates, fitting together the pattern parts, and so on. Before their machining, half-patterns are planed and milled over the jointing plane (the surface of contact between the

half-pattern and the plate) and then mated (to avoid shifting of the half-patterns) by means of locating steel pins.

The machined patterns are mounted on the pattern plates made ready for the purpose, each with the location marks laid out generally from the locating pin. In setting up the half-patterns on the plates, account is taken of the size and design of flasks.

Molding machines commonly use two half-match plates, one for the drag and the other for the cope.

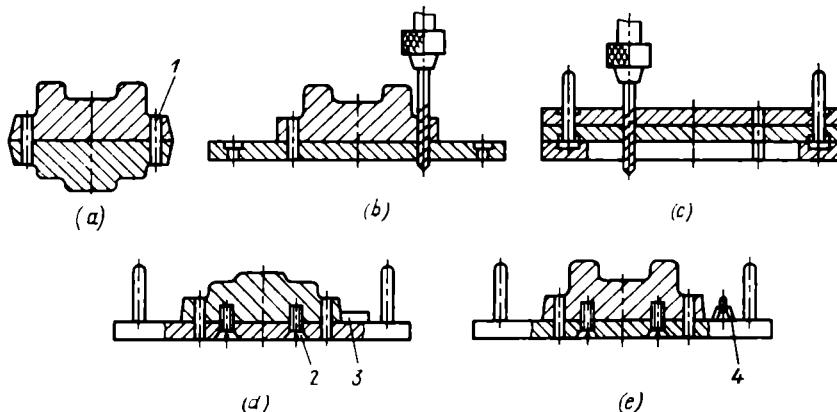


Fig. 23. Mounting patterns on single-sided plates

The patterns of the gating system are fitted on the plate after setting up the patterns of the casting in compliance with the drawing. Fig. 23 gives an example of mounting the patterns on two single-sided plates designed for machine molding. The first steps involve planing as-cast half-patterns over the jointing planes, pairing by means of locating pins 1 (Fig. 23a), turning on the lathe, and tracing axial location lines.

Next, location marks are traced on machined plates (both upper and lower) and then a half-pattern is placed on one of the plates (Fig. 23b) so as to bring the location marks on both parts into coincidence. The half-pattern is now secured in position to drill holes in the plate, using the half-pattern as a drill jig. This done, the clamp is loosened to take off the half-pattern, and the plate is placed with its working surface on the other plate and centered with guide pins (Fig. 23c) to drill holes in the latter plate through the locating holes made in the former plate.

Further, the plates are taken apart, the guide pins are fitted in place, the patterns are mounted on the plates and secured in positions with locating pins to prevent the casting from skewing. Patterns are fastened to the plates from the underside with steel screws 2.

Sometimes gating patterns 3 are bolted to the drag-pattern plate (Fig. 23d) and a slag-trap pattern 4 to the cope-pattern plate (Fig. 23e). Patterns are commonly mounted on single-sided plates with the aid of templates. When installing several patterns on the plate, it is advisable to use a template made from steel sheet 2 to 5 mm thick.

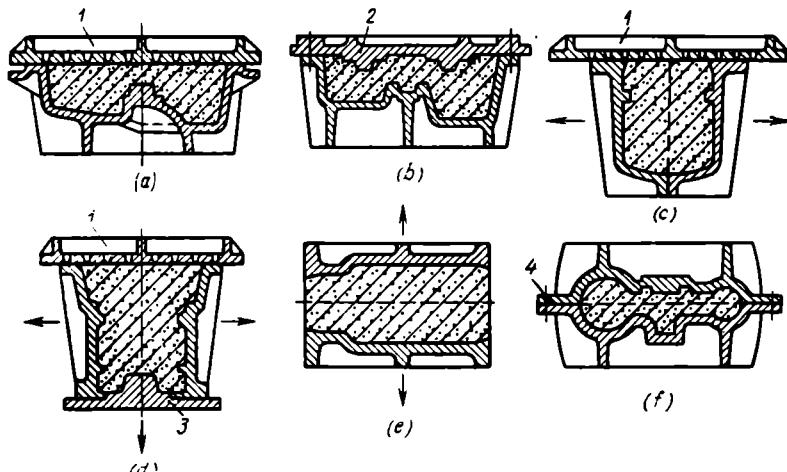


Fig. 24. Basic types of metal core boxes for machine molding

Metal core boxes find use in batch and mass production. The basic types of core boxes are shown in Fig. 24.

Unsplit turnout boxes (Fig. 24a) are applicable for molding cores with one flat side. After ramming the core sand, the box is covered with a drying plate 1 and then inverted and lifted off, leaving the core on the plate. Turnout boxes with insertion pieces 2 (Fig. 24b) are used for the production of shaped cores. In a vertically split core box (Fig. 24c), the core sand is first packed, then a drying plate 1 is placed on top of the box, following which the box is turned over and its walls are drawn apart, thus releasing the core.

Vertically split core boxes with a detachable bottom 3 (Fig. 24d) make a suitable arrangement for forming a depression in the upper part of the core. Core boxes split along the horizontal come in two types, open (Fig. 24e) and closed (Fig. 24f).

The wall thickness for metal core boxes is chosen in compliance with the specifications given in Table 2. To make the box more sturdy, its body is provided with ribs. The thickness of stiffening ribs comes to 0.7 or 0.8 the wall thickness; the edges have 1.25-1.30 times the thickness of the walls.

Before ramming sand into a core box 5, its halves are fixed in position with locating pins and holes and locked together with a swing bolt (Fig. 25a) or a pivoted clamp (Fig. 25b). The swing bolt 1

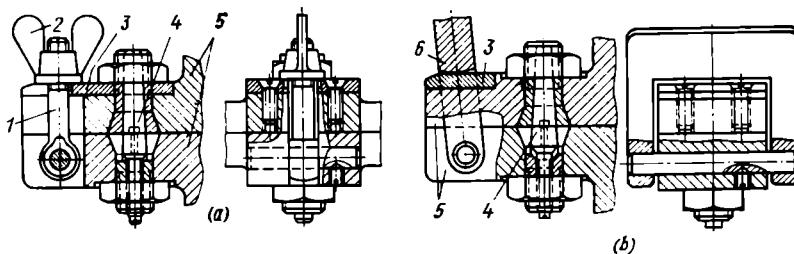


Fig. 25. Design of fasteners for split core boxes

with a fly nut 2 is easy to handle and is light in mass. But it takes much more time to throw on the bolt in place and screw up the nut than just to swing up the clamp 6. To decrease wear on the lugs atta-

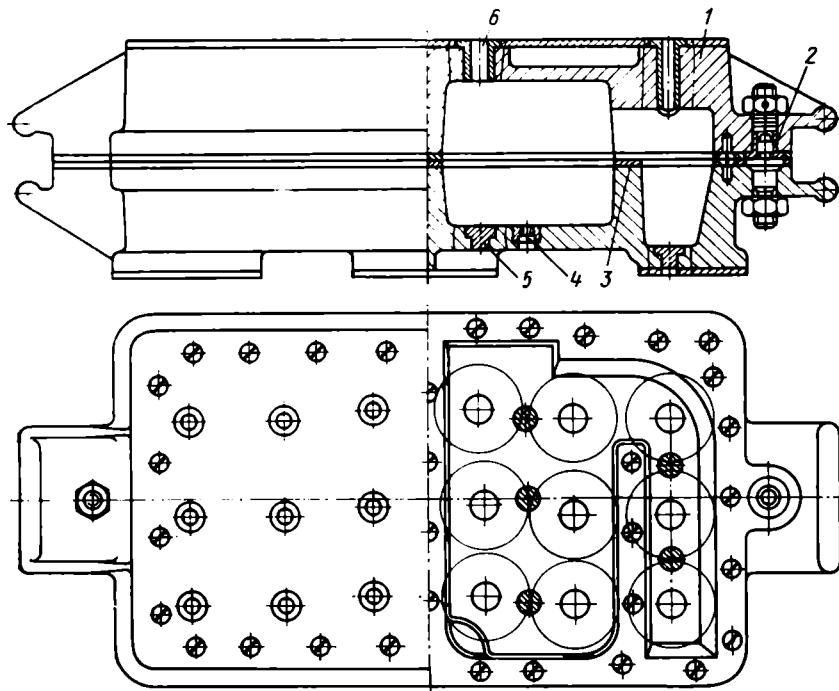


Fig. 26. Metal core box for producing cores in a blowing machine

ched to each half of the box, the lug surfaces are reinforced with steel cover plates 3. Pins 4 fitted into changeable sleeves secure correct location of the two box halves.

Core boxes designed for the production of cores in blowing machines (air sand blowers) have a number of features (Fig. 26).

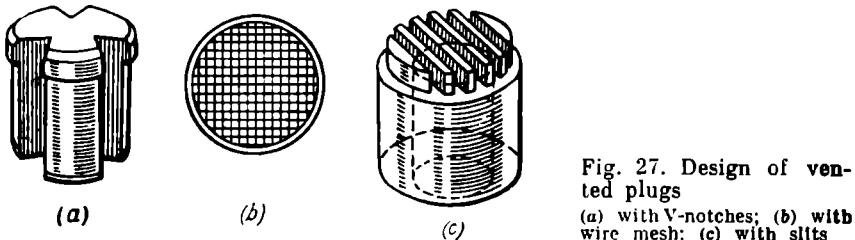


Fig. 27. Design of vented plugs

(a) with V-notches; (b) with wire mesh; (c) with slits

The halves of the core box body 1 made from an aluminum alloy are secured in correct position with locating pins and sleeves 2. To reduce wear of the box halves where they come into intimate contact and to prevent sand from breaking through the box joint, the surface of joint is covered with a ground armor plate 3 fastened to the box casing with screws. An inlet port 6 which serves to admit core sand into the box is furnished with a detachable steel sleeve fitted into it to decrease wear. Also, a replaceable protective plug-insert 5 is pressed into the box wall opposite the inlet port. The plug protects the wall against excessive wear from the abrasive action of the sand jet as it strikes hard on the wall while the machine forces core sand into the box. To allow the air to escape from the box, the walls are provided with vents 4 which are closed by special vented plugs. The plugs (Fig. 27) have fine notches or air strainers which permit the air to force its way out but retain the core sand.

2.4. PLASTIC PATTERNS

The use of plastics for pattern sets facilitates the production process, makes it more economical in cost and labor, brings savings in nonferrous metals, and enables cutting down the stock of machinery employed at pattern shops.

Plastic patterns are highly resistant to corrosion, lighter and stronger than wood patterns. Besides, molding sand sticks less to plastics than to wood. It is particularly advantageous to use plastic stand-by patterns in place of wood patterns and core boxes, for one master pattern can be sufficient for the rapid fabrication of a desired number of doublers.

Various plastics make good materials for the production of patterns. These are the compositions based on epoxy, phenol formaldehyde, and polyester resins; polyacrylates, polyethylene, polyvinyl

chloride, and others. In most wide use are cold-curing plastics based on epoxy resins and acrylates.

Design of plastic patterns. To reduce the mass of patterns and cut the consumption of materials, hollow types are most preferable.

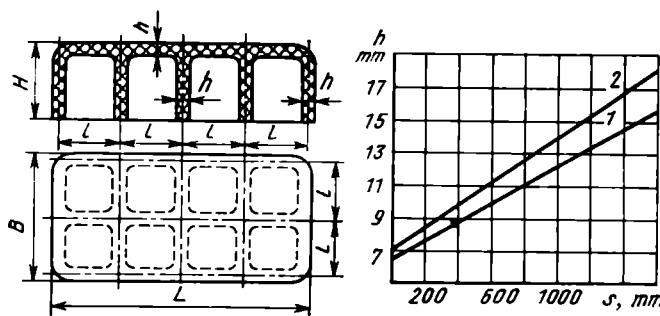


Fig. 28. Design of a plastic pattern casing with stiffening ribs and graphs showing the relationship between the pattern wall thickness and pattern size
1 — epoxy resin; 2 — acrylates

Small patterns about 30 to 50 mm in height can be made solid. The thickness h of pattern walls depends on the overall pattern size s (Fig. 28) and the material employed. Thin-walled patterns are reinforced by stiffening ribs whose thickness is equal to that of the pattern wall. The arrangement of ribs depends on length L and width B of the pattern. The spacing l between ribs is taken equal to two fifths of the pattern height H . Sharp angles at the junctions of walls and ribs are filleted and rounded off to a radius of 3 to 5 mm. Plastic patterns may have smaller tapers (Table 3) than metal patterns since molding sand has a lower coefficient of friction when in contact with plastics.

Table 3
Plastic Pattern Tapers

Pattern height, mm	External wall draft	Internal wall draft
Up to 20	1°	2°15'
21-50	0°45'	1°30'
51-100	0°30'	0°45'
101-200	0°20'	0°30'
201-300	0°20'	0°30'
above 300	0°15'	0°20'

Large thin-walled patterns are plated by wooden, foam-plastic or metal elements. In determining the size of plastic patterns, account is taken of the shrinkage of casting metal and the shrinkage of plastic on curing. Acrylates have a volume shrinkage of 0.4 to 0.6%. Epoxy compounds with fillers do not shrink at all.

The process of production of patterns from cold-setting plastics, such as epoxy resins, includes the stages of making a master pattern, a mold and a desired plastic pattern. The master pattern is made from wood to the second or third class of strength. The master pattern is dimensioned according to the plastic pattern drawing with due regard for machining allowances, mold tapers, and total shrinkage of the plastic and metal cast.

Molds for the production of plastic patterns can be dispensable or semipermanent intended for repeated use. Sand-clay molds are employed for fabrication of large patterns.

Semipermanent molds are made from gypsum. A gypsum mold is first dried in the air and then in the drier chamber. After drying, the mold is sprayed or brushed with nitrocellulose varnish. Before pouring a plastic into the mold, its surface is coated with a parting substance such as grease or machine oil.

For molding a plastic pattern, it is first necessary to prepare a special composition, or compound, from an epoxy resin, filler, hardener, and plasticizer. Epoxy resins are expensive, and therefore the bulk of a compound is a filler composed of metal powders and silica flour (powdered quartz). Fillers give patterns the required strength, toughness, and wear resistance. To obtain a solid epoxy plastic, its composition must include a hardener, or curing agent, such as polyethylene-polyamine, hexamethylene-diamine, and other substances. The hardener induces polymerization of the epoxy resin, with the result that it acquires a desired hardness.

Plasticizers (most often dibutyl-phthalate) are added to the composition to impart toughness to the cured epoxy plastic. The pot life, that is, the storage time (reaction time) of the composition, during which it remains fluid enough to fill in the mold and form the pattern, ranges from one to three hours. That is why the mixture is made ready for pouring just before the production of patterns and core boxes.

The approximate composition of a plastic prepared for pouring (in parts by mass) may be as follows:

Binder—epoxy resin	100
Plasticizer—dibutyl-phthalate, oleic acid	15
Filler—iron powder	200
Hardener—polyethylene-polyamine	20

For preparing the mixture, it is necessary to introduce a plasticizer to the resin and stir the mixture thoroughly, and then add a filler

(iron powder, sand, silica flour) and hardener. In stirring, the mixture heats up to 55°C as a result of the reaction of curing.

The ready mix must be poured into molds 3 to 5 minutes after its preparation as it quickly thickens. Sometimes the filled molds are subjected to degassing for 5 to 10 minutes in special chambers to draw off the bubbles of air from the plastic. The molds are left to stand for 20 to 24 hours to allow the plastic to solidify.

After solidification, the patterns are heat treated to increase their plasticity. Small and medium-size patterns are heated from 50 to 100°C during 4 or 5 hours and then cooled to room temperature. Complex and large patterns and also core boxes are heated up to 60°C, held at this temperature for 30 to 32 hours, and then cooled to room temperature.

After being machined along the parting plane, the plastic patterns are fastened to the pattern plate with pins and screws. The screw heads are sunk into the body of patterns to a depth of 1.0 to 1.5 mm. The depressions are trimmed off, rinsed with acetone and stuffed with putty.

Since epoxy resins are toxic, the pattern shop should have a separate, well-ventilated room for making patterns from these materials.

Patterns made from epoxy resins are serviceable for a maximum of 2 000 half-molds in hand molding, and 30 000 half-molds in machine molding.

Consumable patterns. The patterns are made from a special porous plastic, most commonly from expanded polystyrene. These patterns are used in a full mold process which in essence consists in the following. As molten metal is poured on to the pattern, it immediately burns under heat and disperses through the mold sand, leaving a cavity for the metal. The pattern as a rule closely reproduces the casting in shape, with allowances being made for machining and metal shrinkage, so that the molding process dispenses with the cores in forming cavities, undercuts, and holes in the casting. This simplifies the production of a pattern set, cuts down the time and labor required for its manufacture by 60 to 80%, obviates the necessity for making core boxes, and enables a saving in the materials. Since there is no need here to withdraw patterns from the molds before pouring, the molds are made unsplit, which adds to the accuracy of castings. Expanded polystyrene is a light, porous material with a relative density of 20 to 25 kg m⁻³, melting temperature of 164°C, and dissociation temperature of 316°C. A special grade of polystyrene is available for the production of consumable patterns. This material has a low density, from 18 to 20 kg m⁻³, enhanced strength in compression, from 2.5 to 3 kgf cm⁻², and is capable of rapid dissociation and dispersion, which precludes specific defects in castings.

Polystyrene lends itself to treatment on wood-working machines

and also on special machines where a 0.5-mm diameter nichrome wire heated to 200-300°C serves as a cutting tool. Polystyrene comes in plates measuring from 800 × 900 × 100 mm to 1 000 × 2 000 × 200 mm. The use of these plates enables the pattern maker to do away with splicing, building up, cutting out and bonding together individual parts of large patterns, and thus to facilitate the process of their production. Polystyrene parts can be bonded with the same glues as wooden parts, though it is undesirable to utilize drying water-soluble glues because polystyrene is nonhygroscopic and the glue dries out long. This lengthens the pattern production cycle and may even lead to refuse of castings due to blowholes. Since polystyrene patterns are expendable, they find application in the production of individual pieces or small lots of castings from iron, steel, and nonferrous alloys.

Chapter 3. MOLDING MATERIALS

3.1. GENERAL

Molding materials. Various types of materials are used in foundries for the manufacture of casting molds and cores. They are conditionally divided into *initial* (starting) molding materials, molding and core sands, or mixtures, and auxiliary molding compositions.

Initial molding materials are in turn subdivided into two groups, basic and auxiliary. The first group includes refractory materials such as quartz sands, which form the base, and binders such as clays, resins, and others. The second group covers various additives such as powdered coal, wood flour, and others, which impart desired properties to molding and core sands.

Molding and core sands are prepared from initial molding materials and from *used*, or *reclaimed*, sands. The composition of sands varies with the method of molding, the kind of metal poured into the mold, and the mass and shape of the casting.

Auxiliary molding compositions are washes, cements, and putties required for finishing up molds and cores and correcting minor faults.

For manufacturing high-quality molds and cores and thus sound castings, molding and core sands must have adequate properties compatible with the production process employed.

In order that the molding sand may compact well in the mold, fill in the cavity of a core box and reproduce the shape of a pattern, it must show *plasticity*, that is, the ability to deform under externally applied forces or under gravity. The plasticity of molding and core sand mixtures depends on the properties of ingredients and binders used. For example, a sand mixture with an oil binder exhibits high plasticity; sands with clay-type binders have low plasticity.

A casting mold must possess sufficient *strength* so that it cannot break up in assembling, transportation, and pouring. That is why a molding sand, too, must have a definite strength, that is, the ability to offer resistance to a certain load. The strength of molding sand depends on the grain size (fineness) of sand proper, moisture content and density, which varies with the content of clay binders in the sand mixture. The strength of a molding sand grows with density, clay content of the mix, and decreased size of sand grains.

In testing sand mixtures, it is usual to differentiate between *the strength of a sand in the moist state (green strength) and the strength in the dry state (dry, baked, or cured strength)*. The strength of a molding or core sand after pouring is called *hot strength*. Molds are also tested

for *surface strength*, which is the resistance offered by the mold surface layer to abrasion. The surface strength of a mold depends on *crumbleness* (hardness).

Flowability is the mobility of a foundry sand that permits it to flow into deeper pockets of the pattern and uniformly fill the flask. This property has an influence on the stickiness of sand to bunker walls, on the quality and time of mixing in preparing the sand mix. Flowability is related to *lumpiness*, which is the property of a sand to get lumpy. These two properties depend on the bonding strength of sand grains at places where they come into contact. The increased initial (apparent) density of a sand makes for its more uniform compaction in the mold, therefore a sand mix must exhibit good flowability, or the minimum lumpiness.

In the process of pouring and cooling of the casting, the mold walls heat up to high temperatures, practically equal to the melt temperature. That is why molding materials must possess high refractoriness. This is one of the basic requirements placed on molding materials.

Refractoriness (thermochemical stability) is the ability of a sand mixture to withstand the heat of melt without showing the signs of softening or fusion. This property of a sand mixture depends on the quantitative proportions of ingredients and the degree to which they stand the heat of molten metal. The higher the content of impurities in the sand and clay, the lower the refractoriness of molding and core sands. The refractoriness of a sand mixture grows with the grain size of quartz sand, its content, and with the diminished amount of impurities and silt.

In pouring molten metal into the mold, the organic materials such as binders and sawdust, which enter the composition of a molding sand, convert into gas as they burn. Moisture evaporates in the form of water vapors. The property of a molding sand to evolve gases and steam is called *gas evolution capacity*. It is defined in terms of the amount of water vapors and gases evolved from one kilogram of sand during pouring. The evolved gases, steam, and also air tend to escape from the mold through the pores of the molding sand, which thus must be permeable enough. The property of the molded mass of a sand that enables the sand to allow gas to pass through it is called *gas permeability*. It depends on the quality and quantity of clays and quartz sand in the mixture. The higher the silica content of a molding sand mixture and the larger the sand grain size, the better its gas permeability, and vice versa. Gas permeability is influenced by the shape of sand grains, moisture content, presence of silt, coal, degree of compaction, and other factors. The higher the silt content of sand, the lower its gas permeability. With fast gas evolution and low permeability of a sand mixture, the gas pressure can exceed the pressure of the melt, so that the gas will force its way through the

metal rather than through the sand. This can lead to the formation of gas cavities in the casting.

In the course of cooling and solidification of the casting, its size diminishes because of metal shrinkage. Since the mold retards the contraction of metal, stresses and fractures are likely to appear in the casting. So, a molding sand must display *yieldability*, or deformability, that is, the ability to contract in volume and move under the action of shrinking metal.

High strength and good gas permeability of a molding sand results from its *homogeneity*, that is, uniform distribution of its constituents as a result of mixing.

Molding and core sands must show the least *stickiness*, or *adhesion*, to a pattern or core box. This property is dependent on the moisture content, the amount of a bonding material and its quality. The stickiness of a sand rises with the content of a liquid.

Hygroscopicity is the ability of a molding or core sand to take up and absorb moisture from the air. It depends on the properties of a binder. For example, lignin-bonded cores exhibit high hygroscopicity, therefore the molds complete with such cores should not be allowed to stand long before pouring because this may result in the increased number of castings scrapped as a result of blowholes.

Durability (life) is the ability of a molding sand to retain its properties and be moldable enough in repeated use. The more durable the sand mixture, the lesser amount of fresh molding materials it requires during its reconditioning. This process calls for the removal of dust from the used sand and the addition of virgin sand and clay to restore the original properties of the sand mixture.

Collapsibility is the property of a core that permits it to collapse easily during its knockout from the cooled casting. This property depends on the amount of quartz sand and clay and the type of binder used in preparing core sand mixtures.

3.2. SAND TYPES

The properties of molding and core sand mixtures largely depend on the properties of base sands.

Sands used in the production of molds and cores are mostly loose sedimentary rocks that result from gradual deposition of granular mineral substances and from weathering of deposits of various natural solutions. Sands are mined in quarries, or pits, as a rule by open excavation. They commonly derive their names from the quarries where they are worked. If a sand contains impurities or has an inhomogeneous grain composition, it is enriched in the quarry, that is, cleaned of foreign matter (plant remnants, clay, limestone) and graded according to grain size to obtain graded (washed) or sharp, sand.

Of all the natural sands used in the production of molding and core sand mixtures, *quartz sands* find most widespread application. They occur in abundance in nature, and therefore are cheaper than other types. Besides, they exhibit the desired properties, of which the main one is high refractoriness.

The basic constituent of these sands is the mineral quartz, or silica, of the chemical composition SiO_2 , with a density of 2.5 to 2.8 g cm^{-3} and melting temperature of 1 713°C. In heating, quartz converts into other crystal forms and changes in volume. At 573°C, α -quartz transforms to β -quartz, with the volume varying within $\pm 2.4\%$; at 870°C, β -quartz passes into β -tridymite and changes in volume by 15.1%; at 1470°C, β -tridymite goes into β -cristobolite, now changing in volume by 4.7%; and at 1 743°C, β -cristobolite passes into the melt with a volume variation of 0.1%. Apart from quartz, a sand can contain feldspars, micas, ferric oxides, ferric hydroxides, carbonates, and also argillaceous (clay) minerals. These admixtures give the sand various tinges, impair its properties, and lower its melting point.

In natural conditions, both large and small sand particles settle down on the bottom of water basins. So, sand grains vary in size from a few millimeters to a few micrometers. Conditionally, the grains of less than 22 μm in diameter are referred to the *clay constituent* of sand, irrespective of their chemical composition, and the grains over 22 μm in size to the *sand base*. The clay content of a sand is determined by elutriation, that is, by washing and separating the sand from the clay. Sands are grouped into quartz and clay types depending on the amount of clay they contain.

Quartz sands are the sands which contain not more than 2% clay minerals, 90 to 97% SiO_2 , and up to 8% foreign substances. Sands which contain over 50% clay substances are called clays. The classification of foundry sands according to Soviet standards is given in Table 4.

Shape of grains. Sand grains can be subdivided into round, subangular, angular, and very angular.

For the production of sound castings, the sand must be of a definite grain composition, that is, must have particles of a definite size. The *grain composition* (grain size) of a sand base of molding sands is determined by screening a 50-gram portion of the dry clay-free or clay-bonded molding sand. For this, the sand is first washed and then proportioned for proper size on gage sieves, the normal set of which consists of eleven sieves, each of a strictly definite mesh size, from 2.5 to 0.05 mm (Table 5). As No. 2.5 sieve is covered at the top and a metal pan is placed under No. 005 sieves, the sand portion is screened by means of a special device. The bulk of

Table 4
Classification and Composition of Sands, %

Sand	Class	Clay	SiO ₂ , not below	Foreign substances	
				Alkali-earth and alkali metal oxide, not over	Ferric oxide, not over
Silica, graded	O64K	≤ 0.2	98.5	0.4	0.2
	O62K	≤ 0.5	98.0	0.75	0.4
	O63K	≤ 1.1	97.5	1.00	0.6
Silica	1K		97.0	1.2	0.75
	2K		96.0	1.5	1.00
	3K	≤ 2.0	94.0	2.0	1.50
	4K		90.0	—	—
Lean	T	2-10	—	—	—
Medium-strong	II	10-20	—	—	—
Strong	III	20-30	—	—	—
Extra strong	OIIK	30-50	—	—	—

Table 5
Classification of Sands into Grain Size Groups

Sand	Group	Mesh number of sieve that retains basic fraction
Very rough	063	1, 063, 04
Rough	04	063, 04, 0315
Coarse	0315	04, 0315, 02
Moderately coarse	02	0315, 02, 016
Fine	016	02, 016, 01
Very fine	01	016, 01, 0063
Superfine	0063	01, 0063, 005
Dust-like	005	0063, 005
		Pan

grains caught on three adjacent sieves determines the *basic grain fraction*.

Along with the classes of sands and grain size groups, the Soviet standards classify sands under two categories, A and B. The first includes sands which have a larger amount of basic fraction left on the upper sieve of the three adjacent sieves; to the second category belong sands whose basic fraction is largely caught on the lower sieve.

Quartz sands with an uneven grain composition are grouped into coarse sands, KPK (sieves Nos. 04, 0315, and 02), moderately coarse sands, KPC (sieves Nos. 0315, 02, and 016), fine sands, KPM (sieves Nos. 02, 016, and 0.1), and sands with grains of mixed sizes, KPO, whose basic fraction caught on any three sieves accounts for less than 60% of the portion. For the first three groups, the total residue left on three sieves must be not less than 60%.

The Soviet standard notation for sand grades includes the class of sand, its grain size group (grain fineness number), and category. For example, the grade notation 1K02A reads: quartz sand of class 1K, grain size group 02, and category A; 2K02B denotes the quartz sand grade of class 2K, group 02, category B; T0315A is the notation for a lean sand grade of group 0315 and category A; the grade П025 denotes a medium-strong sand of group 025; and so on.

Use of sands. Medium-strong, lean, and quartz sands of grades П016A, П01A, K016A, K02A, T04A, and others are applicable for green molding of small and medium-size iron castings. Quartz sands of grades K02, K016, K04 find use for green and dry molding of steel castings. Sands of grades П016, П01 are used for molding castings from nonferrous alloys. Quartz sands of grades K016 and K02 make the base of core sand mixtures.

Graded quartz sands of the first, second and other classes go for the production of furan-bonded core mixes. The use of sands containing up to 2% clay lowers the dry strength of core sands.

For obtaining a smoother surface of castings, it is preferable to replace the quartz sand by high-refractory molding materials such as zirconium sand, olivinite, chromite, and magnesite.

Zirconium sand, ZrSiO_4 , shows good heat conduction and high strength and does not weld on to the surface of castings. Its melting point is above 2 400°C.

Zirconium sand is costlier than quartz sand, therefore it goes into the production of facing and core mixes for molding critical castings, and also for the preparation of molding washes applied in molding of large castings. Because of its high thermal conductivity, zirconium sand favors faster cooling of the casting than quartz sand. This offers the opportunity for controlling the process of solidification and cooling of castings.

Olivinite is a magnesia silicate, Mg_2SiO_4 . Its refractoriness is high; the mineral stands up to a temperature of 1 750-1 830°C. Olivinite

sands hold an intermediate position between zirconium and quartz sands in effectiveness and usefulness. Olivinite is most valued in the production of castings from manganese steel because it decreases the surface roughness of castings.

Chrome iron ore (chromite), $\text{FeO}\cdot\text{Cr}_2\text{O}_3$, is added to the composition of facing mixtures used in the formation of molds for large steel castings. The melting temperature of chromite is 1 450-1 850°C, which diminishes with the increased content of iron oxides. Chromite is used in the form of a powder screened through a sieve of 1.5-mm mesh size. After screening, it must have the following grain composition: a 60 to 70% sieve residue on sieves Nos. 1 and 04 and a 30 to 40% residue on sieves Nos. 1 and 063. This material must not contain foreign inclusions which lower its refractoriness. As mentioned above, chromite goes into the production of facing mold and core mixtures and also washes to give a refractory coat to molds used for large steel castings.

Chromite features high refractoriness and volume stability in heating and does not show chemical affinity for iron oxides. These natural properties of chromite permit obtaining castings with lower surface roughness.

Magnesite, MgCO_3 , has a melting temperature of 2 800°C after calcination. Apart from MgO , which results from calcination, the magnesite composition includes calcium carbonate, iron, quartz, and talc. The higher the MgO content of magnesite, the greater its refractoriness. Magnesite does not enter into the reaction with manganese oxides, therefore it makes a suitable material for facing mixes employed in casting high-manganese steel.

Chamotte, $3\text{Al}_2\text{O}_3\cdot\text{SiO}_2$, is a refractory clay calcined prior to sintering. It has high refractoriness, 1 670-1 750°C. Chamotte is used for dry-sand molding of large steel castings.

3.3 CLAY-TYPE BINDERS

Molding clays are rocks consisting of fine-dispersed particles of hydrous aluminosilicates. Clays display binding properties and thermochemical stability, for which reason they can serve as binders in preparing strong molding sands readily peeled off the castings.

Classification of clays. Molding clays fall into four kinds depending on the mineralogical composition: montmorillonite (bentonite), kaolinite, hydromica, and polymineral. Kaolinite and bentonite clays are most popular because they have high thermochemical stability.

Kaolinite, $\text{Al}_2\text{O}_3\cdot2\text{SiO}_2\cdot2\text{H}_2\text{O}$, is a hydrous aluminosilicate with a melting point of 1 750-1 787°C. This mineral is the basic constituent of kaolinite clays.

Bentonite, $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O} \cdot n\text{H}_2\text{O}$, has an unstable chemical composition since Mg^{2+} ions can substitute for a certain portion of Al^{3+} ions in its crystal lattice, and Al^{3+} ions can replace Si^{4+} ions. The crystal lattice of bentonite is able to extend in the direction of one of its axes. This enables bentonite to absorb more water than kaolinite and thus swell, which feature adds to the bonding power of bentonite. The melting point of bentonite lies at 1 250-1 300°C.

Molding clays are divided into grades and classes (Table 6) accord-

Table 6

Classification of Clays by Compression Strength

Clay	Grade	Green compression strength, kPa (kgt cm^{-2})		Class	Dry compression strength, kPa (kgt cm^{-3})
		Bentonite	Other clays		
High-bonding	I	127 (1.3)	108 (1.1)	1	540 (5.5)
Medium-bonding	II	108-127 (1.1-1.3)	78.5-108 (0.8-1.1)	2	343-540 (3.5-5.5)
Weak-bonding	III	-	49-78.5 (0.5-0.8)	3	345 (3.5)

ding to the bonding properties determined from the ultimate strength in compression of a check sample.

The basic constituent which gives refractoriness to a clay is alumina, Al_2O_3 . Admixtures such as lime, alkalis, and various oxides tend to reduce its refractoriness. By refractoriness (thermal stability), clays are divided into three groups, high (T_1), medium (T_2), and low (T_3).

In the notation of clays, the first symbol stands for the kind of clay and the figure- and letter-symbols that follow in sequence identify its grade, class, and group. For example, the notation KIII/2T₂ denotes a kaolinite clay of grade III, class 2, and group T₂.

Use of clays. The choice of molding clays for use in clay-bonded sand mixtures depends on the method of molding employed and the alloy or metal cast. For example, in green molding of iron castings 10 to 50 mm in wall thickness and of small steel castings, the I-III/1-3T₁ types can do well; in green molding of other castings with walls over 20 mm thick, the I-II/1-3 (T₁-T₃) types are suitable; and for dry-sand molding, the I-III/1-2 (T₁-T₃) types of clay are advisable to use.

The selected clay must give the required strength and life to the molding sand and provide for the conditions which would impede the formation of the crust (burnt-on sand) on the surface of castings. It should be kept in mind that the molding sand rich in clay of high

thermochemical stability may prove poorer in refractoriness than the molding sand low in clay or decreased thermochemical stability. Thus, by replacing a kaolinite clay with a smaller amount of a high-bonding bentonite, it is possible to retain the strength and increase the refractoriness of the sand mixture.

3.4. OTHER BINDERS

Binders serve to bond together sand particles and increase the green or dry strength of molding and core sands.

Binders must satisfy the following requirements.

1. Spread out uniformly over the surface of base sands in preparing the molding and core mixes.

2. Give sufficient strength to mixes both in the green and in the dry condition.

3. Impart plasticity to the mix to enable it to fill in all the recesses and pockets in the mold.

4. Show the least stickiness to the surface of patterns and core boxes during the manufacture of cores and molds.

5. Enable fast drying of the core and mold and absorb no moisture during assembly of molds and storage of cores at the storehouse.

6. Evolve a minimum of gases in drying and during casting of the metal into molds and impart the required yieldability to the mold and core.

7. Have the ability not to impair the refractoriness of a molding or core sand, nor to foster burning-on of sand.

8. Contribute to easy knockout of the core from the casting.

9. Be harmless to the operating personnel, that is, not attack the hands or give off noxious gases, and, besides, be cheap and available.

Classification of binders (Table 7). The classification of binders rests on two features, namely, the nature of a bonding agent (organic or inorganic, water-soluble or hydrous, and water-insoluble or anhydrous), and the character of solidification (irreversible, intermediate, and reversible). Aqueous and non-aqueous binders should not be mixed together, for, where this takes place, the mixed binders always reduce the strength of a sand mixture both in the green and in the dry state, in particular if the aqueous binder is a molding clay.

Irreversibly curing binders undergo complex chemical transformations during hardening as a result of polymerization or polycondensation of the substance. Reversibly curing agents such as bitumens, pitches, and rosin restore the properties after cooling, and others such as dextrin and pectic gel do so under the effect of solvents.

Table 7
Classification of Binders

Group	Specific strength, kPa/1% [kgf/cm ² 1%]	Class A		Class B		Class C	
		Curing	Binder	Curing	Binder	Curing	Binder
I	490(5)	Irreversible	Drying oil, Pe-trolatum-base grades, Powdered bakelite	Irreversible	B-1 Carbamide- base grades	C-1 Liquid glass	C-2
			A-1				
II	294-490(3-5)	Intermediate	A-2 Petrolatum- base, Vegetable oil-base grades	Intermediate	B-2 Lignin-base grades	C-3 Cement, clays	C-2
			A-3 Rosin				
III	294(3)	Reversible		Reversible	B-3 Molasses, lignite	Reversible	

Irreversibly curing binders give the highest strength to dry cores, which can amount to 490 kPa, or over 5 kgf cm⁻² for 1% binder. Binders with an intermediate character of hardening impart a medium strength, which ranges between 294 and 490 kPa, or 3 and 5 kgf cm⁻² for 1% binder. Reversibly curing binders give the minimum strength, 294 kPa, or up to 3 kgf cm⁻² for 1% of the binder. Accordingly, binders are divided into three groups depending on what rupture strength they impart to the cores in the dry condition.

Organic binders are broken into two classes, A and B. Class A includes anhydrous and class B hydrous binders. Inorganic binders, which are hydrous bonding agents, form a separate class, C.

Organic chemically curing binders. This group includes anhydrous binders (classes A-1 and A-2) and hydrous binders (class B-1) which give low green strength to mixes, good flowability in the green state, and high strength in the dry state. Such mixes are used for the manufacture of thin-walled shaped cores. Clay, dextrin, and other binders are added to increase the green strength.

Chemically curing binders are subdivided into two groups: oils and synthetic resins. Vegetable, petroleum, and bituminous oils find use in foundry practice.

Vegetable oils include linseed oil and drying oil which has a catalyst added to speed up the process of drying.

Petroleum oil-based binders include such a bonding substance as petrolatum dissolved in white spirit in the proportion one to one. This binder, however, considerably increases the stickiness of mixes, lowers the surface strength of cores, and prolongs the process of drying. Some petrolatum-base binders of improved properties are now available, which are void of the above shortcomings.

Composite binders now in use are the mixtures of several binders. An example is the solution of a vegetable oil and rosin in white spirit. The production of such binders effects savings in expensive and difficultly available oil binders.

Binders of classes A-1 and A-2, such as drying oil, petrolatum-base binders, and composite binders are added to sand mixtures in an amount of 1.5 to 2%. The drying temperature for such mixtures is 200 to 220°C.

The use of the above binders calls for drying of cores. This is a lengthy procedure, which involves a considerable consumption of energy and necessitates a large floor area for driers. That is why foundries make ever extensive use of *synthetic resins* which permit dispensing with the core drying procedure. Both *thermosetting* and *thermoplastic* resins find use as binders. Thermoplasts melt on heating and undergo reversible curing on cooling. Thermosets first soften when heated and then set (harden) as a result of irreversible chemical processes; they are applicable in the production of shell molds and cores. The advantage of such binders is that the process of curing

goes on very fast and results in a strong and elastic film. This markedly speeds up the process of production of cores and molds.

Foundries use most extensively powdered bakelite (phenol formaldehyde resin) mixed with 7 or 8% urotropin (hardener). A sand mixture with a content of this binder from 4 to 6% can show a dry strength from 5.8 to 7.92 MPa, or 60 to 80 kgf cm⁻².

Furan resins (phenol formaldehyde resins with additions of furfuryl alcohol) find wide application in the production of cores in heated molding equipment (hot boxes).

Carbamide resins are the products of condensation of urea and formaldehyde. They dissolve well in water. These resins go into the production of a variety of quick-drying and self-curing binders (class B-1 binders). They give low strength to mixes in the green condition. After drying, carbamide resin-bonded cores become non-hygroscopic and collapse easily. Carbamide resin-based binders find use for the rapid manufacture of cores in heated molding equipment and for the preparation of cold-curing sand mixtures.

Organic air-drying binders. These binders belong to B-2 and B-3 classes. They are water soluble, mix up well with clay and, as a rule, are used together with clay. Clay gives the required green strength, and the binder the dry strength.

Lignin is a by-product of the sulfite liquor of the paper-pulp industry. It is obtainable as a powder or as a liquid. Foundries use concentrated sulfite waste liquor of a density of 1.25 to 1.3 g cm⁻³, containing about 50% dry residue. This is a liquid concentrate. The by-product concentrated to a density of 1.4 g cm⁻³, with a dry residue of 76%, is a dry concentrate. The concentrate with a dry residue of not less than 87% comes in the powder form. Liquid lignin is applicable without additional preparation. The powdered lignin needs dissolving before use.

Lignin-base binders are available in various grades. Examples of these composite binders are the grades consisting of 95% (by mass) lignin and 5% oxidized petrolatum and 80 to 90% lignin and 10 to 20% an appropriate binder. These binders are added to molding and core sands in an amount of 1.5 to 3%. The drying temperature is 160 to 180°C.

Dextrin is a product obtained from starch by the action of a weak acid during low heating. It is used in combination with other binders and also for the preparation of glue for cores.

Molasses is a liquid waste separated from raw sugar in sugar manufacture. Molasses-bonded cores show good yieldability. This binder is sprayed over the surface of cores to add surface strength.

Organic hardening binders belong to class A-3 bonding agents. They are brittle in the solid state and can only be used in combination with clay and lignin. *Rosin* is obtained from the sap of conifers. It enters into the composition of class A-1 binders.

Inorganic binders belong to class C, of which most widespread are clay, cement, liquid silica glass, and plaster of Paris.

Liquid glass is a hydrous solution of silicates of sodium or potassium of the varying composition $\text{Na}_2\text{O} \cdot n\text{SiO}_2 \cdot m\text{H}_2\text{O}$. Liquid glass comes in three grades, with a mixture ratio of 2.61-3.0, 2.31-2.6, and 2.61-3.0. The liquor ratio is found from the formula

$$m = \frac{\% \text{SiO}_2}{\% \text{Na}_2\text{O}} \cdot 1.032$$

where 1.032 is the ratio between the molecular mass of sodium oxide and that of silicon dioxide.

Liquid glass-bonded molding and core sands have a high strength, up to 2.45-2.94 MPa (25-30 kgf cm^{-2}), after thermal heating at 220-260°C or chemical heating (by blowing carbon dioxide, CO_2). The latter method facilitates the production process.

3.5. AUXILIARY MOLDING MATERIALS

These are additives introduced into molding and core sands to improve their properties (gas permeability, refractoriness, yieldability, collapsibility) and also substances which enter into the composition of paints, glues, and parting powders for preparing and finishing up molds and cores.

Antipenetration additives are the materials introduced into sand mixtures to decrease metal penetration into the sand and formation of an adhered layer of sand on the casting face.

Metal penetration or burning-on is penetration of metal between sand grains and also strong adhesion of the fused or sintered sand to the metal of the casting face. The burnt-on sand involves difficulties in cleaning operations and is responsible for rapid wear of cutting tools in machining the castings.

The antipenetration materials which are introduced into a molding sand (depending on the kind of metal and the wall thickness of the casting) are coal dust, black oil, powdered quartz (silica flour), charcoal dust, graphite, and others.

Coal dust (sea coal) is added to facing or unit molding sands in casting iron. Practice has proved that it is most advantageous to use gas-producer or long-flame coals with a low content of ash and sulfur. Before grinding, coal is dried at about 120°C. The residue of coal dust on No. 016 sieve must be not more than 5% and on No. 005 sieve not more than 70%, the balance being the tail fraction. In filling the molds with molten metal, coal dust burns and gives off volatile substances containing the gases CO and CO_2 , which form a gas spacing between the mold walls and metal, so that the metal does not penetrate into the sand.

The amount of coal dust added to the molding sand depends on the wall thickness of castings. The thicker the wall, the more coal dust is introduced into the sand mixture. Thus, the coal dust content of the sand mixture in molding thin-walled castings (5 to 15 mm) varies from 2 to 6%, while for thick-walled castings it amounts to 12%.

Black oil is added to facing sands used in green molding of iron or bronze castings to decrease metal penetration and the burnt-on effect. Since black oil contains little ash, molding sands show good gas permeability and stand up to more handling.

It is desirable to use the black oil that contains not more than 2% ash, 2% moisture, and not over 0.5% sulfur.

Charcoal dust serves as an antipenetration substance for dusting the surface of green-sand molds. Charcoal is ground to powder and screened through No. 01 sieve. Birch and alder charcoals are considered to be the best for the purpose.

Chrystalline graphite is sprinkled on to the surface of green-sand molds in order to exclude the burnt-on effect. It is a high-refractory substance. Estonian powdered shale may serve as a substitute for graphite.

Silica flour makes a good refractory material for facing washes used to give an antipenetration coat to the molds and cores for steel castings. Sometimes it is added to the composition of facing mixes.

Iron-free zirconium is also used for refractory washes applied to molds and cores for steel castings.

Talc is a mineral, a hydrous silicate of magnesium, used for anti-penetration washes, where the binders are bentonite or organic water-soluble substances which give relatively high strength.

Protective admixtures are added to molding and core sands in casting magnesium alloys which are apt to oxidize heavily and burn during pouring and also when they come in contact with the walls of molds and cores. The materials which serve as protective substances are boric acid, sublimed sulfur, and fluoric additives.

Additives that change the heat absorption capacity of molds and cores are useful for initiating directional solidification of a casting or its individual sections.

The heat absorption (storage) capacity of molds and cores is defined by the heat storage coefficient, expressed in $J/m^2 K^{0.5}$,

$$b = \sqrt{\lambda c \rho} \quad (1)$$

where λ is the thermal conductivity of a mix, c is specific heat, and ρ is density.

This coefficient depends on a number of factors such as the mineralogical and grain composition of the sand, its density, moisture content, clay content, and temperature.

Burnup additives decrease the heat storage capacity of a sand mixture since they increase its porosity, diminish the thermal conductivity and density. The additives of this type are sawdust, asbestos, and gypsum. Molding sands of low heat storage are used for facing gate extensions and risers.

The heat storage capacity of molding and core sands can be raised by adding chromite and metal shot. Such sands are intended for the formation of mold and core sections where the metal being poured in should solidify very quickly.

Sawdust increases the gas permeability and deformability of molds and cores. It must be dry and pass through No. 2.5 sieve. Instead of sawdust, one can use peat that contains about 70-73% volatile substances, not over 5 or 6% ash, and up to 25-30% moisture.

3.6. MOLDING AND CORE SANDS

Foundries use a great variety of molding and core sands, or mixtures. The choice of a sand composition depends on the kind of alloy to be cast, the wall thickness, mass and shape of the casting, the requirements the casting must meet, and the type and character of the production process.

3.6.1. MOLDING SANDS

By the use for which they are intended, molding sands are classified into unit (system), parting (facing), and backing (filler) mixes; by the state of a mold before pouring, they are classified into mixes used for molds poured in the green state and mixes for molds poured in the dry state; and by the kind of base sand employed, into natural-bonded and synthetic-bonded sands.

If the mold is formed from one and the same sand mixture, it is usual to refer to it as a *unit* mixture, or sand. Unit sands find use in machine molding in foundry shops producing castings by the piece and in lots. These sands consist of the most refractory base sands and clays of the highest bonding power to ensure a long life of the mixture. In reclaiming the sands for reuse, it is necessary to add fresh materials to make up for the lost properties.

Facing sand is applied to the surface of a pattern and then rammed to form a packed layer 15 to 100 mm thick depending on the thickness of the casting wall in contact with molten metal. This sand is always used with backing sand which fills the rest volume of the half flask. A backing sand must compare to a facing sand in gas permeability.

Unit and facing sands should have sufficient strength so that the mold can stand up to the pressure of molten metal during pouring. The use of facing sand enables one to cut down the expenditure of

fresh molding materials and additives per ton of sound castings. On the other hand, this complicates the production process and involves difficulties in its mechanization.

Refreshing additions are intended for reconditioning of a used sand mixture. They contain virgin sand, clay, and binders in amounts enough to restore the initial properties of the mixture.

Some naturally occurring sands contain such an amount of clay that they make a good molding sand just after moistening and mixing. An example is the Tambovsky sand useful for the manufacture of castings from nonferrous alloys and small castings. Naturally bonded sands have decreased gas permeability and refractoriness.

Synthetic-bonded sands consist of washed or graded sands to which the foundry adds bonding materials such as clay. They find wide application in the foundry practice.

Steel and iron molding sands. Steel and iron castings are made in green- and dry-sand molds. Green-sand molding is a more economical process as it reduces the casting cycle period. But the process has shortcomings: it gives a low green strength so that green molding is practicable for the manufacture of castings up to 3 000 kg.

Dry-sand molds are usually applicable for the piece or small-lot production of moderate-sized and large castings.

The choice of molding sand for iron and steel castings depends on the mass of the casting, its wall thickness, and the molding process.

For green-sand molding of iron castings, it is advisable to use sands bonded with high-bonding clays or bentonite. For dry-sand moldings, clays of a moderate bonding power can serve the purpose. High-bonding clays provide high strength and improved compacting properties (moldability) for the sands.

Granular coal, black oil, and bonding agents such as a sereal binder are added to unit and facing sands to increase gas permeability and strength and improve antipenetration properties.

The sands that go into the production of dry-sand molds for iron castings possess enhanced strength and gas permeability. Such additives as sawdust, peat, and chopped asbestos increase the dry sand deformability.

Table 8 shows the compositions of molding sands used for machine molding in the batch production of iron castings in green-sand and dry-sand molds.

Molding sands for automatic molding. The output and quality of castings and the reliability of the automatic molding process depend on the properties of molding sand and their stability. Automatic molding lines (AML) have high productive capacities, and therefore the rate of sand utilization here sharply grows: the sand operates in more intensive and heavier conditions than in machine molding. This calls for the sands of high and stable properties such as flowability, strength, and gas permeability (Table 9). To ensure these

Table 8
Iron Molding Sands

Application	Casting			Sand			
	Mass, kg	wall thickness, mm	Grain size	Clay content, %	Gas permeability, units	Green compression strength, kPa (kgf cm ⁻²)	Moisture content, %
For green-sand casting	< 20	10-25	01A-016A	8-10	25-50	29.4-49 (0.3-0.5)	4.0-5.5
	20-200	25-40	016A-02B	7-10	40-70	29.4-49 (0.3-0.5)	4.0-5.5
	200-1 000	40-50	02B; 02A	9-12	60-100	39.2-58.8 (0.4-0.6)	4.5-6.0
	1 000-5 000	< 50	02A; 0315A	11-13	100-200	49-78.5 (0.5-0.8)	5.0-7.0
	> 50		0315A; 04A	12-14	100-130	58.8-78.5 (0.6-0.8)	5.0-7.0
For dry-sand casting	To 100	—	02A; 0315A	12-14	60-80	49-78.5 (0.5-0.8)	6.0-7.0
	Over 100	—	0315A; 04A	12-16	80-100	49-78.5 (0.5-0.8)	6.0-8.0
	To 2 000	To 30	0315B; 02A	12-14	70	49-64 (0.5-0.6)	7.0-8.0
	2 000-15 000	50	04A; 0315E	14-16	70	64-78 (0.6-0.8)	7.0-8.0
	10 000-30 000	To 60	04A; 0315E	—	—	Dry tensile strength 147-246 (1.5-2.5)	12-16
For dry-sand casting of large shaped pieces							

Table 8 (continued)
Iron Molding Sands

Application	Sand composition, % by mass						
	Facing sand		Unit sand		Fresh materials		
Used sand	Fresh materials	Coal	Sawdust	Used sand	Coal		
For green-sand casting	78-59	20-38	2-3	—	96.5-94.5	3-5	0.5
	75-45	22-51	3-4	—	94.3-92.3	5-7	0.7
	70-40	26-55	4-5	—	91.0-86.8	8-12	1.0-1.2
	60-40	34-52	6-8	—	—	—	—
	60-40	34-52	6-8	—	—	—	—
For dry-sand casting	70-40	27-57	—	3	—	—	—
	60-35	37-62	—	3	—	—	—
	60-50	28-40	—	10-12	—	—	—
	50-40	38-50	—	10-12	—	—	—
For dry-sand casting of large shaped pieces	20	Sand, 27 Clay, 20	—	13	—	—	—

properties, it is necessary (1) to use high-quality starting materials such as quartz sands of the first and second classes, high-bonding bentonite clays and special additives; (2) comply with the operating procedure specified for the sand preparation equipment; (3) keep a close watch on the properties of sand during its preparation and use; and (4) introduce the required quantity of refreshing materials.

Steel molding sands as a rule include base sands of 1K or 2K class. They contain no less than 95% SiO_2 , and refractory clays of the first grade and the first group (Table 10). The need for high-quality materials stems from the fact that the pouring temperature of steel is higher than that for iron, and, hence, the mold must have increased strength and refractoriness.

Facing sands find use for green molding of small steel castings. It is desirable that the sand may contain bentonite instead of clay and also lignin and liquid glass to give strength to the mold.

In manufacturing light and moderately light castings, it is advisable to use base sands of 016A and 02A grain fineness. The sand of a larger grain size gives a rougher surface finish to the casting. To exclude the formation of a sintered layer of sand on the face of castings, the molding sand should contain up to 20% silica flour providing that it does not impair gas permeability.

In dry-sand molding, quartz sands of larger grain size can be used, though in this case the mold must be given a good coat of wash.

Molds for particularly large castings from carbon steels and special steels, with a wall thickness of over 70 mm, are made with a chromite-base facing sand which consists of 97.5 to 98% chromite, 2 to 2.5% lignin, and 4.5 to 5.5% water. Its green compression strength is 49-58.8 kPa (0.5-0.6 kgf cm^{-2}), the dry tensile strength being not less than 196 kPa (2 kgf cm^{-2}).

The molds for large castings from corrosion-resistant and refractory steels are made with facing chromite-magnesite sands containing up to 7.5% (by mass) of liquid glass that serves as a bonding agent.

Molding sands for fast manufacture of molds (Table 11). In the piece and batch production of medium-size and large castings, the molds are subjected to drying in order to improve the properties of castings. This lengthens the production process and decreases its effectiveness. For cutting down the period of drying or dispensing with it completely, foundries use molding sands with fast-curing organic and inorganic binders.

Sands for skin-dried molds are prepared with organic (lignin-base) and inorganic binders such as a sodium silicate solution (liquid glass). The surface of lignin-bonded sand molds is dried by hot gases. Liquid glass-bonded sand molds are dried by passing the gas carbon dioxide, CO_2 , through the rammed sand in what is called the CO_2 process. It is also possible to skin-dry the latter molds by a gas torch.

Table 9
Iron Molding Sands for Automatic Molding

Application	Composition, % by mass			
	Sand 1K02 10K04	Bentonite- coal suspension*	Bentonite	Granular coal
For casting pieces to 50 kg. Molding on AML by jolt-ramming and squeezing	2.5-5.4	1.2-3.0	—	—
For casting pieces to 10 kg. Molding on AML by jolt-ramming and squeezing	2	1.2-3.0	—	—
For casting pieces to 2 kg. Molding on flask-less automatic lines	3-6	—	0.4-1.0	0.07-1.2

* The composition of bentonite-coal suspension (% by mass) is 18-25% bentonite, 11.6-12.5% granular coal, the balance water.

This treatment gives the mold a strong skin of the desired thickness. The mold is then coated with a wash and dried.

Plastic self-curing sands. These are liquid glass-bonded mixes. The process of preparation includes two stages. The central sand shop prepares the mix base which consists of 92% sand, 5% clay, 3% ground coal, 5.5% liquid glass, and 3.5% moisture. The base is highly plastic, with a green compression strength of 14.7 kPa (0.15 kgf cm⁻²). It is delivered to the molding department in a hopper, from which the mix is fed to the paddle mixer in an amount sufficient to form a mold. At the same time, 2 to 5% ferrochrome slag that serves as a hardener is charged into the mixer. After mixing for 45 to 60 s, the mixture is ready for use as a facing sand. It is sprayed over the surface of a pattern and then the backing sand is riddled into the flask and packed by jolting.

Liquid glass and ferrochrome react in the entire bulk of the mix, so that it hardens. This mix allows for the removal of the pattern as soon as it forms the impression in the mold. In 30 minutes the mold can be given a refractory wash, and 4 to 6 hours later it can be poured. This is an important feature, and is especially so in the

Sereal binders	Used sand	Moisture content, %	Gas per- meability, units	Property		Flowabi- lity
				in green state	in dry state	
0.015-0.05	91-96.3	2.9-3.3	140-180	157-186 (1.6-1.9)	343-588 (3.5-6.0)	66-72
0.015-0.03	95.0-98.8	3.1-3.5	130-170	157-186 (1.6-1.9)	343-588 (3.5-6.0)	70-76
—	92.8-96.5	3.2-3.8	100-125	167-206 (1.7-2.1)	343-588 (3.5-6.0)	67-74

batch production of molds, because the use of other self-hardening mixtures lengthens the machine downtime required for mixture curing and thus makes the process less profitable.

Liquid self-curing mixtures. In the manufacture of molds and cores for large castings made piecemeal or in small lots, a considerable share of work goes to sand ramming operations. The worksaving approach in this case comes to the use of fluid self-hardening mixtures. These mixes show high fluidity so that they can be poured into the flask or core box like a liquid. They are also called free-flowing. Self-curing is another important feature of these mixtures. Intensive mixing of the common liquid glass-bonded sand mixture or the mixture with certain organic binders and special additives causes the formation of foam. The bubbles separate sand grains from one another, make them slide owing to the decreased force of friction and thus add fluidity to the mixture. The fluidity of a mixture can vary with its composition and the period of mixing. The time period during which the mixture retains its fluidity is possible to control. It usually ranges from 9 to 10 min. The mixture must be poured into flasks or core boxes over this time period. The mixture gains sufficient strength in 20-30 min so that it is safe to withdraw the pattern or the core.

Table 10
Steel Molding Sands

Sand	Casting wall thickness, mm, not over	Grain size	Clay content, %	Gas permeability units	Green compression strength, kPa (kgf cm ⁻²)	Moisture content, %	Sand composition, % by mass		
							Used sand	Quartz sand	Clay
Unit, for green-sand casting of plates to 100 kg	0.16A; 0.2A	8-10	80-100	29.4-49 (0.30-0.50)	3.4-4.4	92-90	6.5-8.0	—	1.5-2.0
Facing, for green-sand casting of plates to 100 kg	0.16A; 0.2A	8-10	80-100	29.4-49 (0.30-0.50)	3.5-4.5	80-40	16.5-53.0	3-6.5	
Facing, for green-sand casting of plates to 100-300 kg	0.2E; 0.2A	10-12	100-120	39.2-58.8 (0.40-0.60)	4.0-5.0	75-40	20.5-51.5	4-8	
Facing, for green-sand casting of plates over 500 kg	0.2A; 0.315B	11-13	100-130	99.68.6 (0.50-0.70)	4.5-5.5	60-40	33.5-51.0	6-8.5	To 5.0
Facing, for dry-sand casting of plates; to 5 000 kg	50	0.2A	12-14	70-100 (0.50-0.70)	5.0-7.0	80-40	15.5-50.5	4-9	
to 10 000 kg	50	0.315E; 0.2A	12-15	≥ 81 (0.8-1.2)* (0.55-0.65)	78.5-117.6 (53.9-64)	6.0-7.0	Sand and clay, 100%		
to 10 000-30 000 kg	80	0.315E; 0.2A	12-15	≥ 50 (0.55-0.65)	53.9-64 (34.3-58.8)	6.0-7.0	Quartz flour, 20%, sand and clay, 80%		
For castings* prone to hot tears and surface cracks	80	0.2A; 0.315E	12-14	70-100 (0.35-0.60)	5.0-7.0	80-40	12.5-45.5	4-9	2.4-4.5

* The sand contains 8-12% by mass sawdust.

** Dry rupture strength.

The gas permeability of mixes exceeds 1 000 units, the compression strength, 4 hours after pouring, comes to 196-393 kPa ($2\text{-}4 \text{ kgf cm}^{-2}$).

The use of these mixtures enables the foundry to increase sharply the output of molds and cores per man-hour, exclude manual operations in the manufacture of large molds and cores, eliminate the time-consuming operations of drying, and mechanize the production of large castings.

Cold-curing sands bonded with synthetic resins. These sands are used for the production of medium-sized and large molds and cores both by the piece and in batches.

Washed or graded quartz sands of the first and second classes (noted for a negligible content of clay which lowers the dry strength) form the base of these molding sands. The binders here are carbamide-furan, phenol formaldehyde and other resins (class B-1 in Table 7). The curing catalyst is usually an orthophosphoric acid of 70 to 80% concentration. When mixed with strong acids, the above resins are able to harden and impart high strength to the sand.

The common sand composition includes 100% graded Lyuberetsky sand of first class, 0.5-1.2% orthophosphoric acid (70 to 80% concentration), and 2 to 5% resin. The moisture content of the sand is 0.9 to 1.5%, the life is 1 to 1.5 minutes, and the compression strength after a two-hour holding is not less than 196 kPa (2 kgf cm^{-2}). The life of molding sands is amenable to control by adding catalysts in various proportions. Since the life of the sand is short, it is usual to install the mixer at the site where the mold or core is to be formed and to use the sand directly after its preparation, or, what is done most often, to combine the process of mixing with the process of discharging the sand from the paddle mixer into the flask.

These sands commonly serve as facing materials. Despite the fact that the use of both facing and backing sands here complicates the molding process, the elimination of drying (of large molds in particular) enables a sharp increase in the efficiency of production.

Cold-curing sands present a drawback in that they have low thermal stability, and for this reason the molds must be coated with refractory washes. The ingredients added to these sands are toxic. This calls for proper ventilation to exhaust fumes and dust from the molding shop. The personnel handling the materials must strictly follow the sanitary regulations.

Molding sands for castings from nonferrous alloys. Since the pouring temperature for copper alloys is about 1 100-1 500°C and as low as 750-800°C for aluminum and magnesium alloys, the molding sands used here may be inferior in refractoriness to steel and iron molding sands.

The molding sands for casting copper alloys are prepared from the clay-bonded medium-strong sands mixed with 0.3-0.5% to 1.0-1.5% black oil and used sand (Table 12).

Table 11
Fast-Curing Facing Sands

Application	Sand composition, % by mass			
	Used sand	Sand	Clay	Binder
For iron castings	48-50	3K02A 48-50	4-5	Lignin-base 2.5-3.0
	50-48	3K02 49-50	1.5-2	Lignin 1.0-1.5
For iron and steel castings	—	2K02A	5-8	Liquid glass 5.0-5.5
	40	1K02A 55 Silica flour 5	—	Liquid glass 6.0

Notes: 1. Liquid glass-bonded sand is mixed with 0.75-1% NaOH (10% solution) and

The sands used for casting aluminum alloys are refreshed by adding the clay-bonded sand of grade П01А or П063А.

Molding sands for magnesium alloys must contain protective admixtures to prevent the alloys from oxidation during pouring and solidification in the molds. They should be free of foreign inclusions (coals, shales, and so on) conducive to the formation of blowholes in the castings. A 5 to 8% fluoric addition or 4-5% boric acid addition provides for protection against alloy oxidation. The sands of grade П01А (40-60%) and grade К02Б (60-40%) make up the molding sands for magnesium alloys. The amount of fluoric addition depends on the mass and wall thickness of a casting and the moisture content of the sand. The molding sand intended for castings with walls 30 to 35 mm in thickness must additionally contain 2 or 3% sublimed sulfur.

3.6.2. CORE SANDS

Steel and iron core sands. During pouring, the cores are exposed to much more severe thermal and mechanical effects than the mold because they are surrounded on all sides by the molten metal. For this reason core sands should meet more stringent requirements. The dry strength and the surface strength of a core must be higher than those of a mold. Core sands must have high refractoriness and yield-

Moisture content, %	Gas permeability, units	Strength, kPa (kgf cm^{-2})	
		compression, in green state	tensile, in dry state
4-5	100	24.5-34.3 (0.25-0.35)	374 (3.8)
4-5	60	29.4-39.4 (0.30-0.40)	294 (3.0)
2.4-3.0	150	14.7-29.4 (0.15-0.30)	685-1 180 (7-12)
3-5	100	19.6-34.3 (0.20-0.35)	392-1 470 (4-15)

0.3-0.5% black oil. 2. Sand grade 1K02A is used for steel castings.

ability, low hygroscopicity, particularly in the green condition, high gas permeability and low gas evolution capacity, and good collapsibility.

Cores are divided into five classes according to the geometrical dimensions, configuration, operating conditions in the casting mold, and the requirements imposed on the quality of cast surface (Fig. 29).

Class I includes the cores of intricate configuration and skeleton-type cores with small core prints. These cores form cavities to be left as cast, the surface finish of which must meet high requirements. Cores for casting the parts of internal combustion engines are an example of the cores of this class.

Class II includes the cores of complex shape, having thin projections and crosspieces, along with the massive extensions. They form casting surfaces to be machined either fully or partially.

Class III comprises the cores of moderately complex configuration, which do not have too thin members with massive core prints. These cores form cavities whose as-cast surface finish must satisfy rather high requirements.

Class IV consists of the cores of simple configuration. They form surfaces both subject and not subject to machining, the roughness of which need not comply with stern requirements.

Class V covers the massive cores, which form large cavities in large-sized castings.

The requirements placed on physico-mechanical properties of cores depend on the class of the cores. The cores of classes I and II must show high strength and gas permeability, low gas evolution capacity,

good deformability and collapsibility. A core sand in the green condition must display good flowability, that is, readily fill in intricate pockets of the core box. Class III cores may have a somewhat lower strength, because gases can leave the cores through well developed core prints. These cores must exhibit sufficient deformability and collapsibility. In the initial state, the sands for class III cores may have a lower flowability than the sands for class I cores. The cores of classes IV and V may have a substantially lower strength and gas permeability than class I cores (one-half or one-third the values for the latter cores) because such cores have massive bodies and core prints. But these cores must feature good deformability and collapsibility because they usually form large and long cavities in the castings.

The above requirements placed on the physico-mechanical properties of cores can be satisfied by choosing the requisite composition of the core

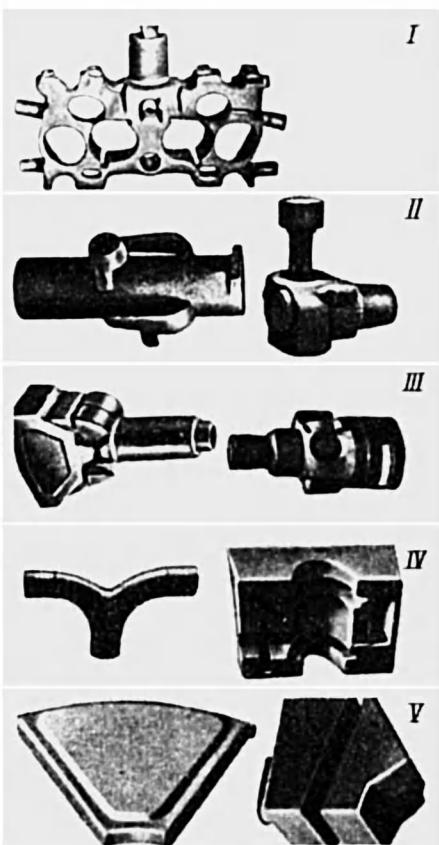


Fig. 29. Classification of cores

sand and the core production method, the choice being dependent on the character of production (either piece, batch, or mass production). The rational choice of the core sand and the production technology secures a high quality of castings and the efficiency of production. Let us consider the compositions, properties, and the requisite field of application of various core sands.

Core sands which require heat treatment for the strengthening of cores include oil-bonded, clay-bonded, and resin-bonded sand mixtures (the bonding resins in the last type of sand are fast-curing synthetic resins).

Table 12
Nonferrous Alloy Molding Sands

Alloy	Composition, % by mass				Properties		
	Sand		Used sand	Additive	Green compression strength, kPa (kgf cm^{-2})	Moisture content, %	Gas permeability, units
	K016A, E	II01 K02A, D II063					
Copper: brasses	10.5	9	80.5	Black oil 0.5-1.5 Ground coal 4	49-58.8 (0.5-0.6)	4.0-5.0	70-75
Aluminum	4.5	10.5	85	—	39.2-78.4 (0.4-0.8)	4.0-5.0	80-90
Magnesium	5-10	5-10	80-90	Fluoric additive 4-8 or boric acid 4-5	39.2-78.4 (0.4-0.8)	4.0-5.0	40-50

Oil-bonded and *clay-bonded* core sands (Tables 13, 14) show satisfactory properties, are comparatively cheap, and suitable for use in hand and machine production of cores in sand blowing, jolt, and squeeze machines. The cores made from these sands require thermal heating to impart strength, which lengthens the production process, lowers the operating efficiency of the foundry, and generates a need for installing driers.

That is why such core sands find application in peacework and short-run work.

Resin-bonded core sands (Table 15) are made with synthetic resin binders of class B-1 (carbamide-base), B-3 (lignin), and class A-1 (powdered bakelite).

These binders are capable of hardening at 230-250°C for a short time (2 or 3 min to 30-50 s depending on the composition and size of cores). Catalysts (both organic and inorganic acids) may be added to speed up the process of curing. The core sand composition also includes such additives as ferric oxide and crystalline graphite, which improve the heat conduction and increase the specific heat of the sand and thereby enable the core to heat through and harden more speedily. Other additives diminish stickiness and improve flowability.

Table 13
Steel and Iron Core Sands

Core class	Composition, % by mass						Property		
	Base		Binder			Wood flour	Gas permeability, units	Moisture content, %	Strength, kPa (kgf cm ⁻²)
Sand 1K02A 1K016	Clay	Used sand	A-1; A-2	B-2	B-3				rupture, in dry state
I	100	—	—	1.5-2.5	—	—	130-150	1-3	2.94-5.8 (0.03-0.06)
II	100-97	0-3	—	2.0-3.0	—	2-3	—	100	2-4 (0.05-0.1)
III	100-96	0-4	0-1	—	3-6	1-3	—	100	3-4 (0.1-0.16)
IV	93-59	7-1	0-40	—	—	2-3	0-2	70	4-5 (0.15-0.25)
V	72-38	8-2	20-60	—	—	2-3	0-3	70	5-6 (0.2-0.35)

Table 14
Core Sands for Nonferrous Alloy Castings

Alloy	Composition, % by mass				Property			
	Sand K016 K02	Clay H01 H016	Blnder	Additive	Moisture content, %	Strength, kPa (kgf cm ⁻²) compression, in green state	rupture, In dry state	Gas perme- ability, units
Copper: bronzes	100	--	--	B-2 (lignin-base) 1.0-1.4	--	3.5-4.5 (0.03-0.05)	2.94-4.9 (4.0-6.0)	392-588 (4.0-6.0)
brasses	86	14	--	B-3 (lignin) 2-3	--	3.5-4.5 (0.06-0.08)	5.8-7.92 (5.0-7.0)	490-685 (5.0-7.0)
Aluminum, using cores; of intricate shape	90-100	To 10	--	B-1 (carbamido- base) 1-1.5 pectic gel 0.5-1.5 A-2 1-2.5	White spirit or kerosene 0.25	2.5-3.0 (0.03-0.07)	2.94-6.85 (5.0-7.0)	490-685 (5.0-7.0)
of less intricate shape	100	--	--	--	--	2.5-3.0 (0.06-0.15)	5.8-14.7 (4.0-6.0)	392-588 (4.0-6.0)
Magnesium, using cores of less intricate shape	90-100	--	T0 10 A-2 or B-3 1.0-1.5	0.5-1.0 sullur and 0.25-0.5 boric acid	2.5-3.5 (0.6-1.5)	58-147 (3.0-5.0)	342-490 (3.0-5.0)	80

Table 15
Core Sand Composition for Cores Prepared in Hot Boxes, % by Mass

Alloy	Binder	Catalyst	Ferric oxide	Crystalline graphite	Calcium stearate
Steel	3.0-3.5	—	1.0	—	—
Iron	2.2-2.7	0.7*	0.7	0.1	0.1
Copper	3.5-4.0	—	—	0.2	—
Aluminum	1.0	0.4**	—	—	—
Magnesium	3.0-3.5	—	—	—	—

Notes: 1. The refractory base of core sands is the grade 1K02 washed sand (100%).
 2. Magnesium core sands contain 1.5% fluoborate of ammonium to protect the alloy from oxidation.

* The mixture of lignin with orthophosphoric acid.

** Carbamide and ammonium nitrate.

The core sand hardens directly in a metal core box heated by a gas or by electrical heaters. These are the so-called hot boxes. The sand hardens as a result of policondensation of a binder (resins of B-1 and B-3 classes) or its polymerization (powdered bakelite). The core gains high strength, up to 9.8 MPa (100 kgf cm⁻²), and gas permeability. Because core sands bonded with the B-1 and B-3 class resins have low green strength, they flow easily and thus readily fill the cavities of complex core boxes. The cores are taken off the boxes already hard, so the castings show improved dimensional accuracy. The core sands deform well, shake out with ease from the castings, but have insufficient thermal stability.

Resin-bonded sands go into the production of cores of all classes for casting thin-walled small pieces 150 to 200 kg in mass from iron, steel, and nonferrous alloys. These sands are prepared from washed sands of the first and second classes, which are more expensive than common quartz sands; the cost of binders is high too, 400 to 800 rubles per ton. The cores are molded in complex, costly metal boxes, so that resin-bonded sands are envisaged for use in high-volume and high-run production. In this case it pays to automatize the production process with a view to increasing the efficiency of manufacture, cutting down the costs, and improving the quality of castings. Along with the sands mentioned above, powdered bakelite-bonded sands are used for the manufacture of hollow shell-type cores. The composition of core sands and the technology of core making are considered in more detail in the Part "Special casting processes".

Core sands which do not call for heat treatment are most promising since they allow the foundry to dispense with the heating of boxes

and to simplify substantially the production process and molding equipment. Cores can be made in wooden, plastic, and metal core boxes. These sands are highly suitable for use in various types of production.

Synthetic resin-bonded cold-curing core sands (Table 16) contain such binders as carbamide, carbamide-furan, phenol-furan, phenol formaldehyde resins (binders of B-1 class). Catalysts are added to speed up the hardening of binders. These are commonly organic and inorganic acids such as benzenesulfonic, orthophosphoric, and nitric acids. The core sands feature high flowability and strength, from 14.7 to 19.6 MPa (15-20 kgf cm⁻²), and also good gas permeability, deformability, and collapsibility.

An important characteristic of a sand mixture is its life, that is the time during which the sand still remains moldable. The life of sands can be controlled by varying the amount of catalyst added to the sand. As the quantity of catalyst increases, the sand life shortens. So, knowing the time it takes to fill the box and ram the sand, we can add such an amount of catalyst as is necessary to provide the desired span of life for the sand.

As the sand hardens, its strength gradually grows. The rate of strength growth is directly proportional to the added amount of catalyst. The maximum value of strength for the given sand decreases with the increased quantity of catalyst.

As the thermal stability of a sand decreases, burning-on becomes more probable. Phenolic and phenol-furan resins feature the highest thermal stability and make suitable binders of sands for steel castings. Carbamide-furan resins have lower thermal stability. They serve as binders of iron core sands. Carbamide resins have the lowest thermal stability. These are the binders of core sands for casting nonferrous alloys.

Cold-curing sands have a lower strength than sands curable in hot boxes, and therefore they largely go into the production of cores of the third, fourth, and fifth classes. The setting time these sands take until they acquire a maximum strength comes to a few hours. The merit of cold-curing sands is that they allow for the production of cores in wooden, plastic, and metal boxes. That is why they have found the widest application in the batch production of moderate-sized and large-sized castings from iron and steel. The use of these sands makes it possible to exclude drying, mechanize the core production process, improve the quality of castings, and increase the output.

Cold-curing silica-bonded sands include core sand mixtures with a liquid silica glass as a binder. The cores are dried by blowing carbon dioxide through the rammed sand (see Table 11). They can also harden under heat. The core sands have high strength, good gas permeability, but show low deformability and poor collapsibility.

*Table 16***Synthetic Resin-Bonded Cold-Curing Sands for Cores in Molding**

Application	Sand composition, mass %	
	Binder	Catalyst
For casting pieces to 1 ton, in batches	Resin 2.8	Orthophosphoric acid 1.8
For casting pieces to 4 tons, piecemeal and in small lots	Resin 2.5	Orthophosphoric acid 1
For casting pieces 5 to 10 tons, piecemeal and in small lots	Resin 2.0	Benzenesulfonic acid (65-80%) 1.2-1.4

* The refractory base of core sands is the grade 1K016 sand (100%).

Sawdust (about 1.5%) and asbestos powder (up to 5%) make the cores more deformable and collapsible. These core sands are applicable in the piece and batch production of steel and iron castings.

Liquid self-set core sands, which compare in properties to the above described sands, have come into extensive use in the batch production of large castings. The use of these sands enables the foundries to raise the output per man-hour, mechanize the process of production of cores for casting parts both piecemeal and in small lots, and improve the quality of castings.

3.7. WASHES, PASTES, POWDERS, AND OTHER DRESSINGS

Core and mold washes and pastes are called upon to prevent metal penetration or burning-on, increase the surface strength, decrease the crumbleness of mold and core walls, and provide clean surfaces and smooth casting appearance. Antipenetration washes consist of refractory materials, which form the base, and binding agents. The washes applied to the surface of mold and cores form a strong refractory coating which keeps the molten metal and its oxides from penetrating into pores between sand grains and thus eliminates the burnt-on effect.

Molding washes. These paints must conform to the following requirements: (1) have a high melting temperature to stand up to the fusion effect of contacting metal; (2) produce no fusible compositions when in contact with the metal; (3) remain invariable in composition during preparation, storage, and when in use; (4) have good covering capacity; (5) form a strong skin on mold and core walls, free of

Iron and Steel Castings*

Sand property				Life, min	Time of hardening in box, min
Tensile strength, kPa (kgf cm ⁻²) after holding, hours					
1	2	3	4		
294-392 (3-4)	490-588 (5-6)	685-785 (7-8)	980-1 270 (10-13)	1.5-2	6-7
147-245 (1.5-2.5)	294-392 (3-4)	490-785 (5-8)	1 470-1 960 (15-20)	11-15	40
—	—	—	588-685 (6-7)	8-9	35-40

cracks after drying; (6) firmly adhere to the mold; (7) contain as little foreign matter and difficultly available materials as possible.

The choice of washes depends on the kind of metal cast, mass of the casting, and molding method. Washes for large iron castings contain such antipenetration materials as black lead with the additions of bentonite and binders. In washes for small and medium-size iron castings, silica flour mixed with coal and ground coke substitutes for graphite. Washes for steel castings usually consist of silica flour or zirconium silicate, which serves as a refractory base, mixed with the same binders as those used for iron castings.

In casting iron parts, it is advisable to add 5% coal and charcoal dust to the wash in order to create a reducing atmosphere in the mold; silica flour, graphite, and ground anthracite account for 95% of this reducing wash.

The compositions of washes for molds and cores of iron castings are given in Tables 17 and 18.

The steel molding washes of the 2nd, 3d, and 4th types are put to use for cores in casting steel parts with walls 20 to 40 mm in thickness.

In painting cores or molds, it is advisable to stir the wash regularly to make it stay in suspension. When applying the wash on cores by dipping, one should shake off the excess of wash to avoid influxes and insure against sealing of the vents. It is good practice to check the coat tightness and its surface hardness by applying the wash to sample molds and cores or to standard specimens.

To enable a better sticking of the wash to the surface of molds and cores, foundries make use of priming paints consisting of 25% lignin, 75% water, and 25% pectic gel. The paints are applied by the common methods.

*Table 17***Compositions of Core and Mold Washes Used in Production of Iron Castings, % by Mass**

Type of wash	Silica flour	Pectic gel	Bentonite	Graphite	Coke	Talc	Water	Density, g cm ⁻³
1	—	3.0	3.4	53.4	—	—	40.0	1.30-1.35
2	34	3.4	3.7	17.0	17	—	24.7	1.30-1.35
3	34	3.4	3.7	9.0	17	—	23.7	1.35-1.45
4	—	—	4.0	—	—	61	35.0	1.40-1.45
5	—	—	3.0	30.0	—	31	33.0	1.40-1.45

- Notes:* 1. The first three types contain 0.2% naphthenate soap.
 2. The fifth type of wash contains 3% molasses as a substitute for pectic gel.
 3. The fourth type is applicable in casting aluminum, and the fifth in casting bronze.

*Table 18***Compositions of Core and Mold Washes Used in Production of Steel Castings, % by Mass**

Type of wash	Silica flour	Bentonite	Naphthenate soap	Water	Binder	Density, g cm ⁻³
1	72	1.65	1.25	18.0	Pectic gel, 7.1	
2	72	3.0	0.5	14.0	Lignin, 7	1.40-1.50
3	78	3.0	0.5	15.0	Dextrin, 3.5	
4	76	3.0	0.5	8.5	Molasses, 12	1.50-1.55
5	76	3.0	0.5	8.5	Lignin, 12	

Air-drying washes speed up the process of drying of coated molds and cores. The composition of a wash of this type includes 10% crystalline graphite, 12% black lead, 3.5% polyvinyl butyral, and 74.5% solvent 646 (or a solution of ethyl acetate and alcohol in the proportion 1 to 1). This wash is applied to molds and cores for iron castings. In the wash used for steel castings, graphite is changed for zircon.

Pastes. If washes do not give a sufficiently smooth casting surface, nor ensure the desired dimensional accuracy of castings, it can be useful to apply pastes on to the surface of cores to exclude surface blemishes. Pastes find rare uses, however, because they involve manual labor.

Coating pastes are made anhydrous. They usually consist of four parts crystalline graphite and one part vegetable oil (by volume).

Sometimes lignin serves as a binder instead of the expensive oil, and talc together with graphite makes the base. After applying the paste, the cores are dried at 220-240°C.

It is advisable to use oil-free pastes of the following composition (% by mass): 50% talc, 15% chamotte, 25% crystalline graphite, and 15% clay. The dry powder is then dissolved in 0.6 or 0.5 l of water per kg dry mass. If the paste is applied to a hot core, the coat does not require additional drying.

Putties. These find use for repairing purposes and for sealing seams which may form while cementing the cores. It is only the cores which have small cracks and dents in unimportant places that are subject to repair. The cores with open fissures and large fractured parts are considered unrepairable. The putty of the following composition is most popular: 65% grade 2K0063 sand, 25% crystalline graphite, and 10% molding clay screened through No. 016 sieve. The ingredients are properly mixed, and the mass is then blended with water (0.3 l water for 1 kg powder); powdered soap is added in an amount of 0.5% by mass to give plasticity.

A putty applied to the cores for steel castings consists of 40% refractory clay, 30% silica flour, and 30% quartz sand; the powder is then mixed with 2% lignin and 13% water.

Core cements (pastes). These serve to bond together core halves molded in two core boxes. The composition commonly includes water-soluble binders, clay, and bentonite.

In wide use are the core pastes of the following compositions: (1) 50% lignin, 50% molding clay, 20% water (the rupture strength of dry paste is not less than 685 kPa, or 7 kgf cm⁻²); (2) 40% dextrine and 60% clay mixed with water (65 parts water to 100 parts by mass of powder).

Parting powders and dusts. Patterns and core boxes are dusted with facings to prevent the molding sand from sticking to their surfaces. Powders form a water-impermeable coat and thus exclude sand adhesion. Foundries use a lycopodium powder and its substitutes for the purpose.

The *lycopodium powder* is a white to yellow substance, which is light in mass, fluid and fine-grained (it fully passes through No. 0063; No. 005 catches 5% powder). This powder is costly and not readily available.

Artificial dusts (substitutes for lycopodium powder) are produced from fine powders of tripoli, dolomite and other similar materials. The powders are treated with paraffin, fat, and wax to provide a thin film on powder grains.

Other materials which prevent sand sticking are kerosene with crystalline graphite or the mixture of 10% oleic acid and 90% kerosene. Heating a pattern plate to 40°C also helps eliminate sticking. The film of kerosene on the pattern surface precludes its moistening.

ning with water and thus excludes sand adhesion. For economy, the mixture may consist of 50% kerosene and 50% black oil. Heating the pattern dries its surface and thus impedes moisture condensation if the sand is still hot.

3.8. PREPARATION OF MOLDING AND CORE SANDS

Molding and core sands are the mixtures of fresh molding materials such as base sand, clay, binders, additives, and used sands. Depending on the mass of pieces cast, the amount of molding sand required to mold 1 000 kg of sound castings varies from 500 to 1 300 kg, and that of fresh materials from 500 to 4 000 kg.

Production process. The process of preparation of clay-bonded sands involves several basic stages: the pretreatment and preprocessing of fresh molding materials, reconditioning of used sands, and preparation of the mixture from the ready fresh and reclaimed sands, additives, and binders.

Preliminary stages involved in the preparation of molding materials. Modern large foundries are not engaged in the pretreatment of virgin molding materials since they receive them ready for use: the base sand is dried and washed and the clay and coal are dried, ground, graded and packed. However, many foundries use fresh molding materials in the green condition. Where this is the case, the fresh materials are preprocessed: the sand and clay are dried and screened, the coal and clay are mulled and ground in millers.

Various drying ovens are available to foundries to dry sands and clays. Most popular are drum-type and horizontal ovens. Fresh sand is dried at 250°C. The output of these ovens is 5 to 20 t/h and over.

Dry clay is crushed in mullers or ground in ball mills and then screened to obtain a powder. Ball mills grind clay and coal to a fine powder. The output of mills is 100 to 8000 kg/h.

Dry clay is often replaced by a clayey or clay-coal suspension (a mixture of clay or clay and coal with water). The use of suspension enables dispensing with a number of operations involved in the preparation and transportation of bentonite and clay, for here the materials do not need drying and grinding.

Reconditioning of used sands. A used molding sand requires pretreatment prior to reuse.

Nonmechanized foundries employ either a conventional riddler or a mobile sand preparation unit to screen the used sand and separate metal and other particles from it.

In mechanized foundries, the used sand travels from the shakeout screen on a belt conveyor to the sand preparation station for breaking loosely bonded lumps and cooling in special units.

Large lumps of sand of the broken molds are generally crushed by plain or grooved rollers. Metal particles are removed by magnetic separators installed at the sites where the used sand slips off from one conveyor on to the next (Fig. 30). The belt 1 with sand 2 bends round a pulley 4 with a built-in electromagnet. Nonmagnetic particles of sand slide off the belt, while magnetic particles 3 such as solid droplets of metal, rods, and mold reinforcement pins go on moving with the belt. As the magnetic action of the pulley ceases, they fall into a bin 5.

Next, power riddlers screen the sand to make it ready for moistening to a preset moisture content and for cooling by passing the air through it, which also carries away dust. The belt conveyors then discharge the sand into bins (hoppers) of the sand preparation station for reuse.

Preparation of molding sands. One of the important stages in the preparation of sand is mixing of its ingredients. Proper mixing is necessary for the uniform distribution of components over the entire bulk of sand.

During mixing, clays and binders envelope sand grains, lumps disintegrate, and moisture uniformly spreads over the entire volume. A properly mixed sand shows high strength and enhanced gas permeability. Sand preparation stations use mixers, called mullers, where the main working elements are wheels and plows.

Mullers of the periodic and continuous types are available. The periodic-type mullers mix sands in batches. A batch of sand is charged into the muller, mixed, and then unloaded. In the continuous mixers, charging, mixing, and discharging are carried out simultaneously. The latter mixers are most suitable for automatic processes.

There are centrifugal-type mullers and mullers with vertical wheels.

Figure 31a shows the periodic-type muller with vertical wheels. Such mullers are usually used at medium- and small-capacity foundries.

Foundries of high production capacities use continuous centrifugal-type mullers such as shown in Fig. 31b. As seen, vertical shaft 8 carries a crosspiece 9 from which wheels 1 are suspended on swings or crank arms 10. The crank arms are hinged to the crosspiece. As the vertical shaft 8 begins to rotate, the wheels 1 move toward the wall of pan 11 under the effect of centrifugal force. The limiter, however, restrains the further movement of wheels, so that they stop short of the wall. A controllable gap thus forms between the wall and the wheel working surface.

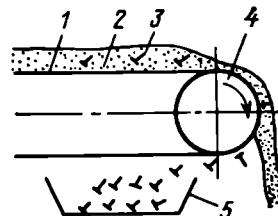


Fig. 30. Scheme of operation of a magnetic separator

Unlike the common muller wheels, here the wheels move along the wall of the pan rather than over its bottom. Plows 7 fastened to the crosspiece 9 are set up so that they lift up the sand from the pan bottom and push it under the wheels. The time of mixing in the centrifugal muller is 1 to 1.5 min. The ready batch is discharged by the plows through a hatch in the bottom of the pan. The hatch is

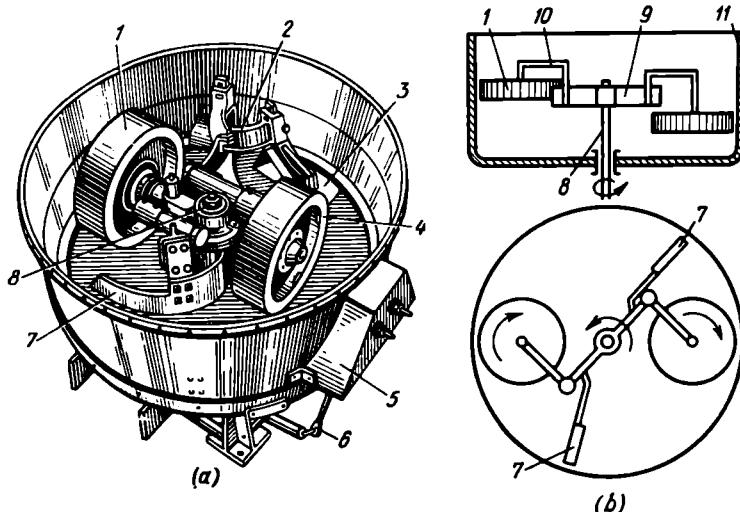


Fig. 31. Muller with vertical wheels (a) and centrifugal-type muller (b)
 1 and 4—wheels; 2 and 7—plows; 3—hatch in the pan bottom; 5—housing; 6—tie rod;
 8—vertical shaft; 9—crosspiece; 10—crank arm; 11—pan

pushed open by a pneumatic cylinder. The sand in the pan is cooled by an air blower.

Sequence of steps in loading the ingredients. The dry materials are charged first into the muller. These are the base sand, clay, and used sand. The materials are mixed dry for about 1 to 3 min and then moistened. Where the use is made of a clayey or clay-coal suspension, the moisture content is controlled by adding the suspension and water. After moistening, the sand is mixed again for a few minutes. The binders are charged last. The time of mixing is 2 or 3 min for the backing sand, 1.5 to 2 min for the unit sand, and 5 to 10 min for the facing sand.

Such a procedure of loading the components is suitable for the preparation of molding sands in the mullers of low capacities. In the automatized molding processes, the sequence of charging and preparation of sands is different if the foundry employs high-productive mixers (Table 19). First a portion of water is poured into the muller in order to prevent the sand being loaded and the resultant

Table 19
Sequence of Steps in Sand Preparation

Operation	Time, s
Feeding water into the muller	6
Feeding fresh and used sands and removing dust	8
Feeding bentonite-coal suspension	12
Feeding sereal binder	12
Mixing and aerating	110
Discharging	14

mixture from sticking to the pan walls. The new and used sands are then charged into the pan and blown through by an air jet to remove the fines. Following this, the bentonite-coal suspension and sereal binder are fed into the muller, and the ingredients are mixed for 100-110 s and aerated at the same time. The finished mixture is discharged into proportioning hoppers (batchers) which deliver it to the mold preparation line.

Preparation of the molding sand in the automatized molding process. Automatic molding involves the use of complex sand preparation systems. These systems usually consist of two groups of equipment: one prepares the molding sand and the other reconditions (reclaims) the circulating (used) sand.

Figure 32 illustrates a scheme of one of the sand preparation systems. The dry sand travels on a belt conveyor 1 to hoppers 2 installed above the muller. The used sand passes through a shakeout screen 3 of the automatic molding line and falls on a conveyor 4, which also collects the spill of molding sand from molding automatic machines 5. The conveyor 4 transports the used sand on to the belt of conveyor 6, where a magnetic separator 7 suspended over the belt takes off metal particles from the sand. Next, the crusher breaks up the lumps, aerator 8 loosens the sand, riddler 9 screens it, and the overhung magnetic separator 10 removes the remaining metal particles from the sand. Further, the conveyor carries the sand into a drum-type homogenizer 11 for tempering it to a preset humidity by water fed into the drum through injector nozzles. The sand then goes from the drum 11 into an evaporate cooler, which represents a chamber 12 with a moving slat-type conveyor. The sand slips off on this belt and the air passed through the sand cools it and simultaneously carries away the silt. As it leaves the drum, the sand has a temperature of

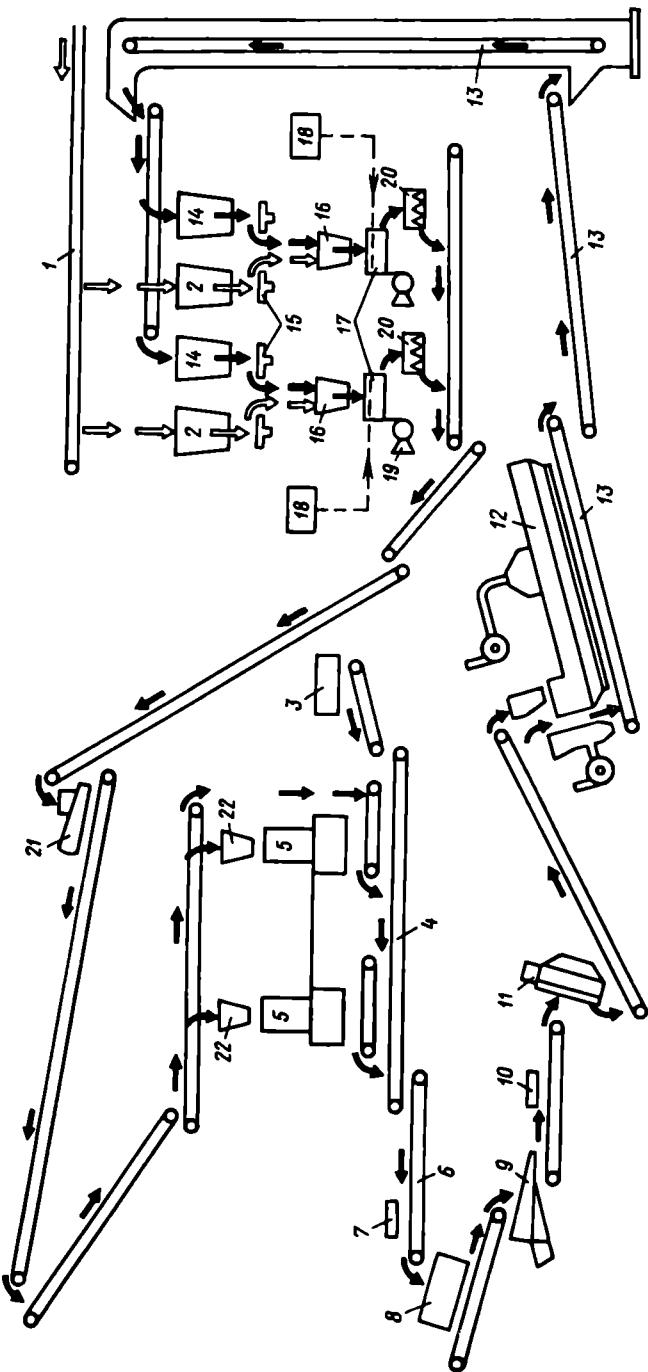


Fig. 32. Scheme of an automatic foundry sand preparation system

not over 38-40°C. The conveyors and elevator 13 transport the sand into hoppers 14 set up above the mullers.

Pan feeders 15 then discharge the dry and used sands from the hoppers 2 and 14 into batchers 16 of mullers 17. The unit 18 prepares a bentonite-coal suspension, which flows into the mullers through pipes. After mixing the sand for 110-120 s, the mullers discharge the molding sand into batchers 20. Fans 19 which pass the air through

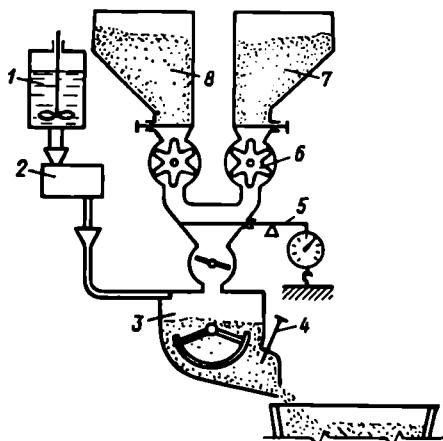


Fig. 33. Schematic of a periodic-type mixer for preparing liquid self-curing mixtures

the sand during its mixing act to cool it and remove dust. The sand then travels from the batchers 20 on belt conveyors to an aerator 21, from which belt conveyors transport it to hoppers 22 placed above the automatic molding machines.

Preparation of quick-drying sands. These sands are usually prepared in muller-type mixers. First, dry materials (used sand, clay, fresh sand, and additives) are loaded into the muller and mixed for 5 min, and then binders and water are fed into it. The ingredients are then intermingled for 7-10 more minutes. The ready mixture must be allowed to stand before use for a few hours.

In preparing the liquid glass-bonded quick-drying mixtures, it is well to load first the sand and clay into the muller and blend them for 2 or 3 min, then add caustic soda and mix for 3 or 4 min, following which it is necessary to add liquid glass and mix for 10-12 min. Black oil comes last. The mixing procedure than lasts 4 or 5 more minutes.

Preparation of liquid self-curing mixtures is carried out in paddle or revolving-arm mixers of the periodic or continuous type. Fig. 33 shows the scheme of a periodic-type mixer for the preparation of liquid self-hardening mixtures. Mixer 3 receives sand from a hopper 8 and ferrochrome slag or slime from a hopper 7. The materials go into the mixer through a feeder 6 and weighing batcher 5. Then a liquid

composition consisting of liquid glass and special additives is allowed to flow into the mixer 3 from a container 1 through a batcher 2. After mixing during 4 or 5 min, the ready mix moves into a flask or core box through a door 4. Periodic-type mixers are applicable in the manufacture of small-sized cores. Continuous-type mixers are adaptable for the long-run production of cores. During mixing,

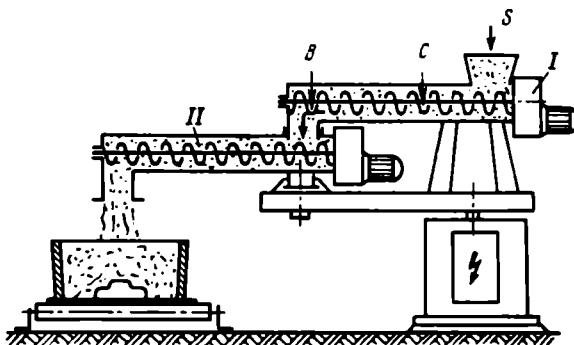


Fig. 34. Schematic of a screw-type sand mixer for preparing cold-curing mixtures

foaming agents quickly convert the mixture into the liquid state. Its life depends on the ratio between a binder and a hardener. As the hardener content increases, the life of the mix diminishes.

Preparation of synthetic resin-bonded cold-curing sands is carried out in paddle or screw-type sand mixers (Fig. 34) with a rotational speed of $0.5\text{--}0.6 \text{ s}^{-1}$ (30–36 rpm). The sands are commonly prepared in such a sequence: the dry sand S and catalyst C are discharged from the batchers into section I of the mixer, where the materials are mixed for 2–2.5 min. A binder B is then added from the batcher at the end of section I . The final operation is performed in section II , where the sand, catalyst, and binder are mixed for 1.5–2 min. The ready molding sand is discharged from section II into a core box or flask.

Preparation of sands for the production of cores in hot boxes. These sands are prepared in mullers having pan capacities of 200 to 500 kg. The sequence of charging the components is the following. First the sand and then a catalyst are fed into the muller and mixed for 1–1.5 min, and afterwards a binder is introduced. The mixture is then blended for another 1 to 1.5 minute period. The ready sand mixture is transported into the receiving hopper of mullers, from which it is conveyed to the hoppers of coremaking machines.

In manufacturing large cores, it is good practice to place a fast-running mixer alongside a core sand blower, so that the mixer can

discharge the ready batch of sand into the core box. Such a production process permits increasing the catalyst content of sand and shortening the core hardening time. Of course, the life of the core sand decreases here, but it is of little importance since the sand goes for molding directly after its preparation. The foundry is thus able to raise the output, cut off time for transportation, and increase the effectiveness of the production process.

Reclamation of molding and core sands. The process of reclamation (renovation) of the used sand consists in removing a portion of

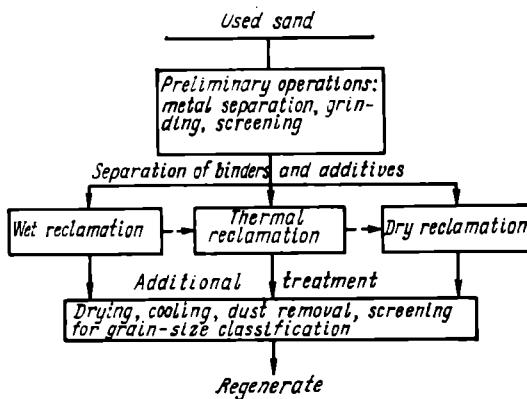


Fig. 35. Flow-chart showing the steps in reclamation of molding sands

sand from the black sand mixtures and restoring the original properties of the sand. The need for reclaiming the used sand arises from the requirements the foundries must meet in order to prevent the pollution of the surrounding medium. Moreover, the reclamation of sands results in a more rational utilization of valuable sand deposits and in a decrease of casting rejects. Conversion to new chemical binders permits the reduction of fresh sands to 3 tons per ton of castings.

Foundries make use of various sand reclamation methods (Fig. 35). The first stages include the magnetic separation of metal particles from the sand, grinding, and screening. The next stages involve the removal of binders and additives from sand grains by resorting to suitable techniques. The choice depends on the sand mixture composition, the nature of binders and additives, and also on the conditions of production, the mass of castings, the foundry capacities, and on other factors.

Wet reclamation is usually applicable at foundries equipped with hydraulic and hydroblast installations for cleaning the castings. The scrubbing effect of water and the effect of solvents combine to strip

off the clay and the salts of sodium and phosphorus from sand grains. The washed sand free of silt is then dried and screened for grain-size classification. The sand so reclaimed then goes for the preparation of molding sands. Thermal reclamation is commonly adaptable for restoring the properties of synthetic resin-bonded cold-curing and hot-curing sands, oil-bonded sands, and, more rarely, clay-bonded sands. The essential units of the thermal sand-reclamation system are fluosolids kilns and vibrating screens with infrared burners. The sand in the kiln heats up above 800-900°C, the binder films enveloping the sand grains burn out, and the clay substances readily peel off as they lose strength. This method is comparatively expensive for it necessitates complex units.

Dry reclamation permits the removal of clay particles and the coke residue of binders from the sand grains as they bounce in the stream of air or rub one against another. The method uses disintegrators, hammer mills, pneumatic scrubbers, and other units. The sand reclaimed by any of the above described methods need be additionally treated, freed of fines, and then screened for grain-size classification.

The choice of a sand reclamation method depends on the type of molding and core sands destined for regeneration. Liquid glass-bonded sands, mixes utilized in the CO₂-process, liquid and plastic self-curing mixes are least amenable to reclamation. The reclaimed sand (regenerate) changes the properties of molding and core sands according to the type of binder, catalyst, and the method of hardening employed. That is why the addition of regenerate to a molding or core sand calls for adjustment of its composition in order to obtain the set properties.

3.9. SAND CONTROL

3.9.1. TYPES OF CONTROL

Control over the properties of initial molding materials, molding and core sands, and auxiliary compositions is one of the essential elements of the control system responsible for the quality of products turned out by the foundry. In order that the molding and core sands may meet quality requirements, it is a standing practice to subject all initial molding materials delivered to the foundry to acceptance inspection.

Acceptance inspection of molding sands is a sand-control operation intended to determine the grain composition of sand, its grain fineness number (size range index), the clay content, moisture content, and refractoriness. For synthetic resins, the test procedure involves the check of the basic characteristics to make sure that they conform to the specifications. This is the task of the acceptance inspection

group at the laboratory of molding materials. The time intervals at which the sand control operation is to be conducted depend on the function the shipped materials must serve and on the stability of their properties. If the supplier delivers new materials, or changes one material for another, or a new supplier ships the materials, then the acceptance inspection procedure must follow, the purpose of which is to check the materials to see that they meet the specifications. Obviously, the foundry can reject the materials which do not satisfy the tests.

Control over the molding and core sand mixtures consists of the quick analysis and the complete control procedure.

The *rapid analysis* of unit facing and backing sand mixtures is called upon to determine the green compression strength, moisture content, gas permeability; the core sands destined for drying are tested for the green compression strength, moisture content, rupture strength in the dry condition, and gas permeability; the sands curable in the molding equipment are checked for the rupture strength (of set specimens), life, compression strength (for chemically hardening sand mixtures after holding the samples in the air), and gas permeability.

Complete control over the molding and core sand mixtures includes the tests for determining the properties as specified in the technological instructions of the given foundry.

The *frequency of sampling* for the rapid analysis of unit molding sands at the foundry using over $100 \text{ m}^3/\text{h}$ sand for the high-volume production of castings must not be less than 2 times an hour; at the foundry consuming less than $100 \text{ m}^3/\text{h}$ sand, the samples must be taken not rarer than at hourly intervals; and at the foundry consuming less than $50 \text{ m}^3/\text{h}$ sand for small-lot production of castings, the time interval must not be longer than half an hour.

The samples of facing sands are taken from every batch at the moment when half the batch has gone off the mixer; backing sands are checked two or three times, the samples being taken at the sites of molding.

Core sands are sampled not rarer than two times per shift, the samples being taken when half the batch has been discharged from the mixer; where the continuous-type mixers handle the sands, the samples can be drawn at two-hour intervals.

Molding and core sands which harden in the molding equipment need be checked not rarely than two times every shift, the samples being withdrawn when half the batch has been discharged from the sand preparation unit.

The samples, commonly not less than 1 kg in mass, should be kept in sealed containers.

3.9.2. RAPID-TESTING TECHNIQUES

Determining the clay content of sand. The clay content of molding sand is determined by elutriation. For this, the laboratory worker empties a 50-gram portion of sand dried at 105-110°C into a one-liter

glass can (flask) and adds 475 cm³ distilled water and 25 cm³ 1-% solution of caustic soda, NaOH. Then he fits the can on the stirring device, called the sand washer, or elutriator (Fig. 36) and keeps it running for 1 hour at a rotational speed of 60 min⁻¹.

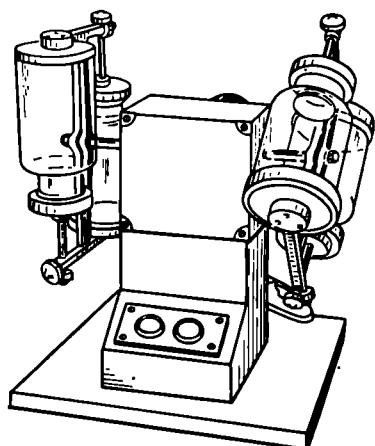
Now the worker takes off the can, adds more water level with a 150-mm graduation mark, and places the can on the table to allow the sand to precipitate for 10 min. The sand grains settle down to the bottom, while the clay substances remain in the suspended state. Next, he siphons off a column of turbid water 125 mm in height,

Fig. 36. Stirrer

then adds fresh water to top up the previous level, stirs the flask again, and holds it for another 10 min. Then he draws off the water, adds fresh water again to top up the same level, stirs the flask, allows it to stand now for 5 min and then siphons off cloudy water. He repeats the last cycle as many times as is necessary until the water in the can becomes transparent, which is an indication that the sand is completely free of clay. The technician now filters the sand left in the can and dries it on the filter gauze at 105-110°C. This done, he weighs the residue to 0.01 gram. The difference in mass between the initial sample (50 g) and the residue shows the clay content of the sand.

Determining the grain-size composition of sand. The grain composition of a sand is determined by screening a dry elutriated sample 50 grams in mass. The sand portion is screened on a special device, called the sieve shaker, or laboratory sifter (Fig. 37), which includes an electric motor and a cam drive that shakes in the horizontal plane a stack (bank) of sieves arranged in order of decreasing mesh sizes, from 2.5 mm for No. 2.5 sieve to 0.05 mm for No. 005 sieve. Prior to testing, it is necessary to cover No. 2.5 sieve by the lid and put the pan under No. 005 sieve. The device executes about 300 vibrations per minute. While the device is running (for 15 min), the driving arm strikes on the lid at a rate of 180 strokes a minute.

The screening being over, the operator takes off the stack of sieves



from the device and weighs the residue of sand grains left on every sieve. The results are expressed in percent of the initial 50-gram portion. Weighings are made accurate to within 0.01 g. The material

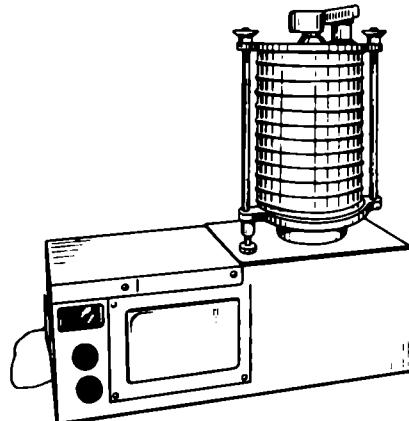


Fig. 37. Device for determining the sand grain-size composition

that has passed through all the sieves into the pan is weighed too. This residue is denoted as 'pan' or tail fraction.

The sum total of the residues caught on all the sieves together with the tail fraction and the clay must be equal to 100%. The sand caught on any of the sieves is called the fraction, whose grain size is designated by the number of the given sieve. The grain-size composition of sand is determined from the largest bulk of grains caught on three adjacent sieves.

Table 20
Factors Used for Determining the Grain Fineness Number

Sieve No.	Mesh size, mm	Factor	Sieve No.	Mesh size, mm	Factor
2.5	2.5	—	02	0.20	53
1.6	1.6	5	016	0.16	65
1	1.00	9	01	0.1	105
063	0.63	20	0063	0.063	165
04	0.40	30	005	0.05	210
0315	0.315	40	—005	<0.05	300

Using the data given in Table 20, we can calculate the grain fineness number:

$$a = \frac{\sum a_i g_i}{\sum g_i} \quad (2)$$

where a_i is the factor, taken constant for the given mesh size of sieves, and g_i is the residue caught on each sieve, expressed in percent of the portion.

Knowing the grain fineness number, we are able to control the ratio between the coarse-grained and fine-grained fractions of the sand. If this number goes beyond the permissible limits, the gas permeability of the mold decreases, which may result in blowholes, surface depressions and other defects in castings. Addition of the coarse fraction of sand to the sand mixture levels off its grain composition and remedies the situation.

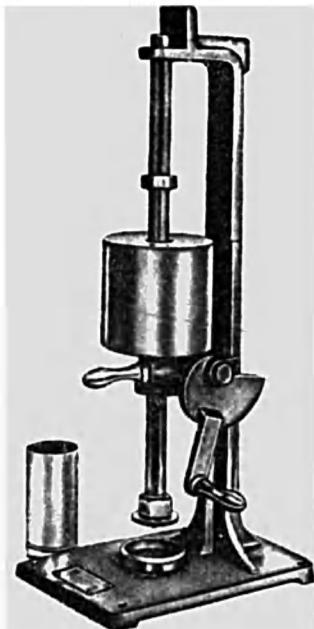


Fig. 38. Drop hammer for the production of specimens

cylindrical specimen so produced has a diameter d of 50 ± 0.2 mm and a length l (height) of 50 ± 0.8 mm.

The technician then places the specimen with the shell in a meter (Fig. 39) for determining its gas permeability by passing through the specimen $2\,000 \text{ cm}^3$ air. Registering the air pressure at the inlet into the shell (ahead of the specimen) and knowing the time it takes the air to pass through, it is possible to calculate the gas permeability of the molding sand by the formula

$$k = \frac{Ql}{Fpt} \quad (3)$$

where Q is the volume of air passed through the specimen, cm^3 ; l is the specimen height; F is the cross-section area of the specimen, cm^2 ; p is the pressure in the device chamber ahead of the specimen, mm WG; and t is the time the air takes to pass through the specimen.

To speed up the gas permeability test procedure, one can set up

plates with calibrated orifices of 0.5 or 1.5 mm in diameter in the space between the device bell and the specimen. The first plate is suited for testing the materials whose gas permeability does not exceed 50, and the second for the materials in which this variable is likely to be above 50. In running the test with the plates, the pressure under the bell (with the three-way cock closed) must be 100 mm WG. The air ($2\ 000\ \text{cm}^3$) passes through an orifice 0.5 mm across for 4.5 min, and through an orifice of 1.5 mm across during 0.5 min.

Knowing the air pressure, we can calculate the gas permeability for the given plate. The manuals or instructions for application of the meter give the tables that enable determining the gas permeability from the pressure registered ahead of the specimen under test. The specimen tested for gas permeability is then subjected to the test for determining its green compression strength. In the devices of new makes, the values of gas permeability of the specimen being tested are read off directly from the scale.

Determining the moisture content. A molding or core sand portion of 50 g (accurate to 0.01 g) is placed in a drying cabinet to dry it at $105\text{--}110^\circ\text{C}$ to a constant mass. After cooling, the sand portion is weighed again. The lost mass (in grams) against the initial mass of the wet portion gives the moisture content of the molding set, expressed in percent,

$$w = \frac{Q - Q_1}{Q} \cdot 100 \quad (4)$$

where Q and Q_1 are the sand portion mass before and after drying respectively, g.

Figure 40 shows the device (known as the moisture teller) for rapid estimation of the moisture content. Here the sand portion is dried for 3 min, using the radiant energy of the lamp. The moisture content is found from formula (4).

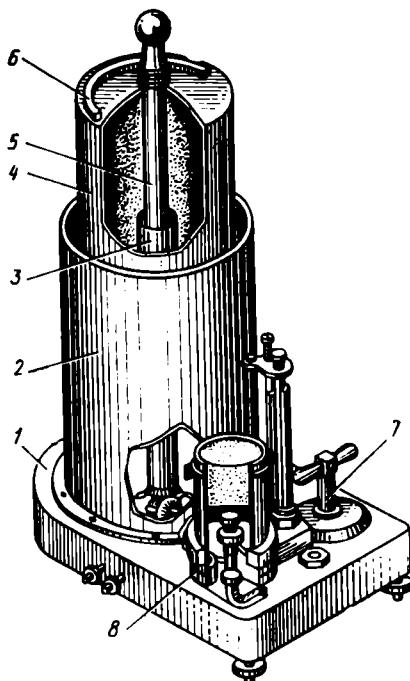


Fig. 39. Gas permeability tester
1—base; 2—tank; 3—tube; 4—bell; 5—guide tube;
6—weight; 7—three-way cock;
8—shell

Determining the sand strength. Specimens are tested for strength both in the green and in the dry condition. The procedure of determining the green compression strength involves testing of standard cylindrical specimens ($d = 50 \pm 0.2$ mm and $l = 50 \pm 0.8$ mm)

without shells. These are the specimens which have been previously tested for gas permeability. The green compression strength of specimens is determined by using the device as shown in Fig. 41a:

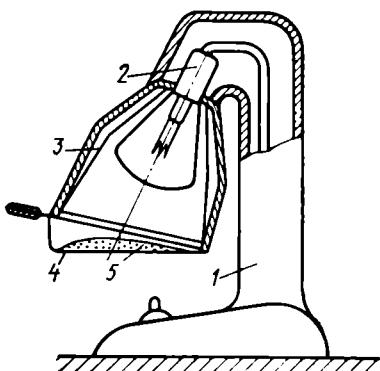


Fig. 40. Device for rapid estimation of moisture content
1—stand; 2—lamp; 3—reflector; 4—pan;
5—sand sample

where P is the collapsing force, Pa (kgf); and F is the cross-section area of the specimen, cm^2 .

The tensile strength of dry molding sand is found by testing dry specimens shaped as the figure 'eight'. A specimen is molded in a split core box and compacted with three blows of the weight on the

standard rammer. After drying and cooling, the specimen is tested for tensile strength in the device shown in Fig. 41b. In the devices of modern design, the values of tensile strength are read on the scale.

Rapid testing techniques for core sand mixtures hardening in hot molding equipment. Figure-eight test specimens (Fig. 41c) find use here for estimating the tensile strength, and cylindrical specimens 50 ± 0.2 mm in diameter and 50 mm in height for estimating the compression strength. The specimens are heated in compliance with the procedures specified for the process of production of cores, taking into account the type of binder, catalyst, and so forth. The testing is conducted on not less than three specimens. If the test results for any of the specimens deviate more than 10%, not less than three tests are performed again on new specimens. The gas permeability of core sands is determined in the following manner. The sand portion sufficient for the production of a cylindrical specimen is emptied into the shell heated to the temperature of binder hardening and rammed with one stroke of the rammer. The specimen with the shell is then placed into a drying cabinet and held there as much time as is necessary at a temperature sufficient for the binder to harden. After cooling, the specimen with the shell is placed in the device for determining its gas permeability.

Techniques for rapid testing of synthetic resin-bonded cold-curing

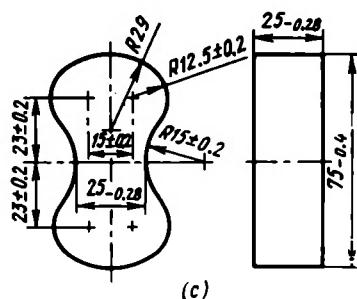
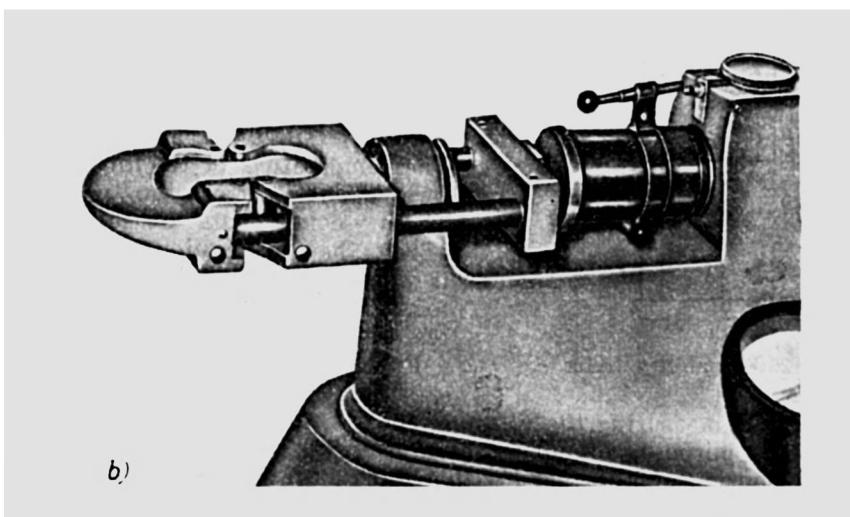
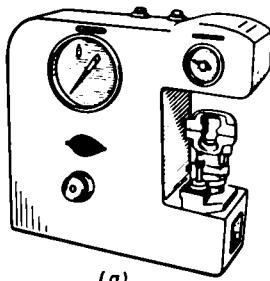


Fig. 41. Green compression strength tester (a); rupture strength tester (b); and figure-eight test piece (c)

sands. The methods given above are also applicable here for determining the compression strength and gas permeability. A very important characteristic of these sands is the life, that is, the time during which they still remain moldable. The life of sands is determined by using compression-test or tensile-test specimens which are subjected

to tests at certain intervals of time. The life of sand is defined as the time (in min) elapsed from the moment of its preparation up to the moment when it loses not more than 25% of its strength.

Techniques for testing liquid self-curing sand mixtures. In the laboratory conditions, the test batch (of not less than 5 kg but not over 15 kg) is prepared in a periodic-type paddle mixer with the shaft rotating at a speed of 75 ± 1 rpm. The temperature of the initial materials and the air must be $20 \pm 2^\circ\text{C}$. The dry components are mixed for 1 min, then the liquid composition is added, and the mass is blended for 2 more minutes. In 1 or 2 minutes, the mixture is ready for testing.

Flowability (fluidity) of the sand mixture is determined by the

method of measuring the ultimate shear stress of a liquid mixture. For this purpose, foundry laboratories use the device (Fig. 42) which consists of a bracket 1 with a guide bush 2 and screw stopper 3, a knife 5 with a stem rod 4, a scaled rule calibrated in shear stress units (dyne cm^{-2}), and a cup 6 for the mixture being tested. The inside surface of the cup is coated with a parting oil to keep the mixture from sticking to the cup walls.

The technician lifts up the knife with the rod until the free end of the rod becomes coincident with the zero of the scale and then fixes the knife with the stopper. He fills the cup with the mixture up to the brim, cuts off any excess level with the upper edges of the cup, and then loosens the stopper to let the knife fall down and submerge into the mix. As the knife has stopped moving down, the technician reads off the depth of submersion from the scale. The ultimate shear stress (in dyne cm^{-2}) is found by the formula

$$\theta = \frac{98.1G}{2bl} \quad (6)$$

where G is the mass of the knife with the rod, g; b is the knife blade width, cm; and l is the depth of knife penetration, cm.

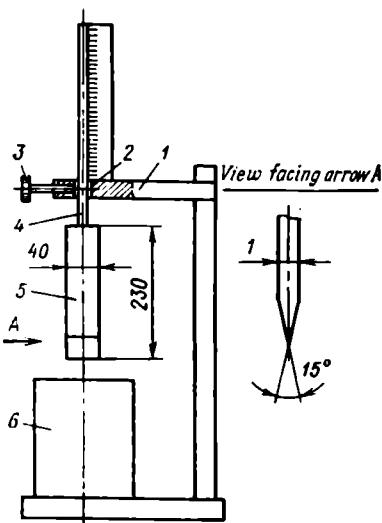


Fig. 42. Flowability tester

Determining the foam-generating capacity and foam stability of the solutions of surface-active agents. The properties of liquid self-curing mixtures, primarily flowability, depend on the foam-generating capacity of surface active substances. For determining the above mentioned properties of solutions, laboratories use the device which consists of a drive, measuring cup, and impeller whose rotational speed is 2 000 to 5 000 rpm. The technician empties into the cup 100 cm³ of the 5-% aqueous solution of foaming agent with a binder, allows the impeller to run for 30 s to beat up the foam, and then measures its volume. In 30 min he measures the foam volume again, and then calculates the foam-generating capacity (in %) from the formula

$$FC = \frac{V_f}{V_i} 100 \quad (7)$$

where V_f is the volume of foam produced, cm³; and V_i is the initial volume of solution, cm³.

The foam stability may be found from the formula

$$FS = \frac{V_{f_0}}{V_{s_0}} 100 \quad (8)$$

where V_{s_0} is the foam volume in 30 min, cm³. The values of FC and FS are calculated accurate to 0.1.

Chapter 4. PRODUCTION OF MOLDS

4.1. GENERAL

The process of forming molds, called molding, is an important operation involved in the manufacture of castings. After preparing molds at the molding shop and making cores at the coreroom of the foundry, the next, equally important operation that follows is the assembly of molds for pouring. As regards the degree of mechanization of molding processes, there are hand, machine, and automatic types of molding. Machine-building plants employ hand molding to cast one or few pieces, for example, in initiating pilot production, or unique pieces, or important repair parts. Machine molding is adaptable to batch and large-lot production and, rarely, to piece production, and automatic molding to high-volume production of castings.

4.1.1. TOOLS FOR HAND MOLDING

The molder uses various tools (Table 21) as he forms, repairs, and finishes up the mold. By the purpose they serve, the foundry tools can be divided into two groups.

The *first group* comprises the tools used for filling the flasks with sand, ramming it, and forming vents in the mold. These are shovels, riddles, hand and pneumatic rammers, vent wires, and others. The spirit level intended to check a pattern for its horizontal position also belongs to this group.

The *second group* includes the tools for drawing patterns from the molds and for finishing operations. These are hemp swabs and brushes, lifting screws and draw spikes, mallets, trowels, mold repair lifters, spoons, and slides (beads) of various shapes.

4.1.2. FLASKS

Casting molds are largely formed in flasks (molding boxes), which are rigid frames of rectangular, square, round, and irregular shapes made of iron, steel, and aluminum alloys. Flasks protect the molds against damage during assembly, transportation and pouring (Fig. 43). Cast or welded steel flasks are considered to be more suitable for the purpose than iron boxes because they are stronger.

The mold is usually prepared in two half flasks, the upper, called the cope, and the lower, known as the drag.

Table 21
Foundry Tools

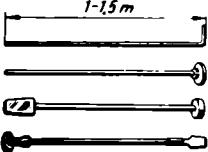
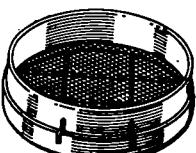
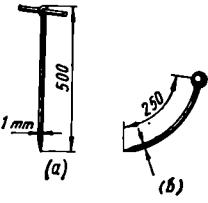
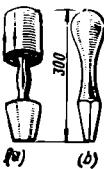
Tool and its application	Tool and its application
Spirit level 	Long hand rammers 
For aligning flasks, adjusting straight edges in pit molding, and so on	For packing large molds, pit and floor molds. Wedge-shaped rammers are used to compact sand at flask walls, around the pattern, in narrow areas; flat rammers are used to compact upper layers of the mold
Riddle 	Pneumatic rammer 
For screening molding sand, particularly for applying parting (fac-ing) sand to the pattern. Riddles vary in mesh size. The diameter of round riddles is 400 to 500 mm	For hand molding and also additional ramming in machine molding. Wedge-type or flat tips are changeable
Shovel 	Vent wires 
For digging pits in pit molding and loading sand into flasks	For forming gas escape channels in molds and cores. Wires: (a) straight; (b) curved
Hand rammers 	
For ramming sand in flasks or core boxes when operating on benches. Rammers: (a) wooden; (b) iron. Rammers have rubber tips to keep the pattern from damage	

Table 21 (continued)

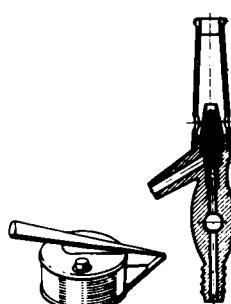
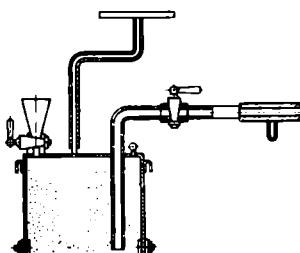
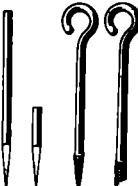
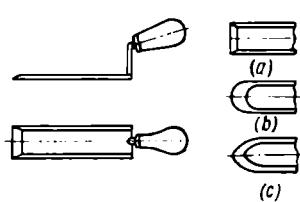
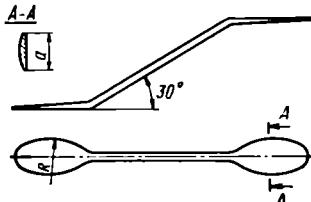
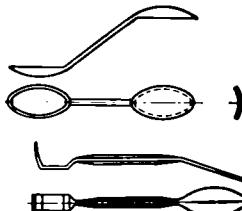
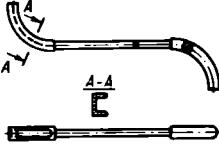
Tool and its application	Tool and application
Mallet	Sprayers
	
For rapping the pattern to withdraw it from the mold and for stripping the core box from the core	For moistening the mold surface prior to finishing operations, and for applying antipenetration washes and solutions to strengthen the surface of molds and cores
Draw spikes and lifting screws	
	For withdrawing the pattern or its detachable parts from the mold
Swab	For applying a thick coat of refractory material on the working surface of molds and cores
	Trowels
For moistening the mold over the contour of the pattern prior to its withdrawal, sometimes for wetting the damaged portions before repair	
	For finishing operations. Trowels: (a) square-nosed; (b) round-nosed; (c) tapered

Table 21 (continued)

Tool and its application	Tool and its application
Double-enders (sleekers)  For smoothing the walls of molds and cores	Spoons  For trimming and repair of molds and cores
Mold repair lifters  For finishing and repair of molds	Slides (beads)  For finishing and repair of molds
	Blast nozzles and air pumps to remove dust and loose sand

The surface of half flasks along the parting line is planed and, sometimes, polished to secure a tight joint between the cope and drag.

Small flasks are fitted with grips for ease of transportation and handling during molding, and large flasks with lifting trunnions for crane transport. The flask walls have vent holes for the escape of gases evolved during pouring molten metal into the mold. In large-sized flasks, the molding sand is held in place by ribs or cross-bars.

Elements for centering half-flasks. The important elements which provide for the accuracy of assembling of the molds are pins and holes in the lugs of flasks. There are two ways of securing the correct location of half-molds, with a loose (removable) pin and with a fixed pin. In the first method (Fig. 44a) the loose pins placed into the pin holders of the cope are inserted into the holes in the lugs of the drag.

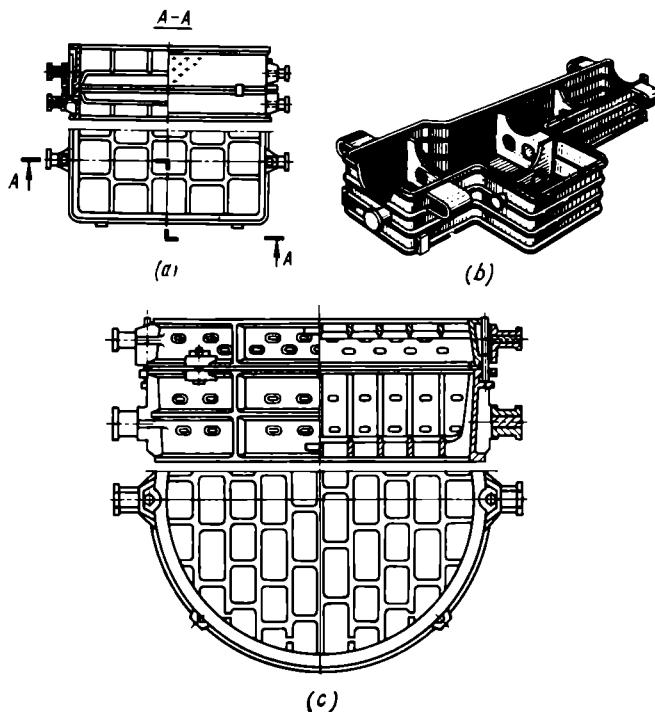


Fig. 43. Types of flasks
 (a) rectangular; (b) shaped; (c) round

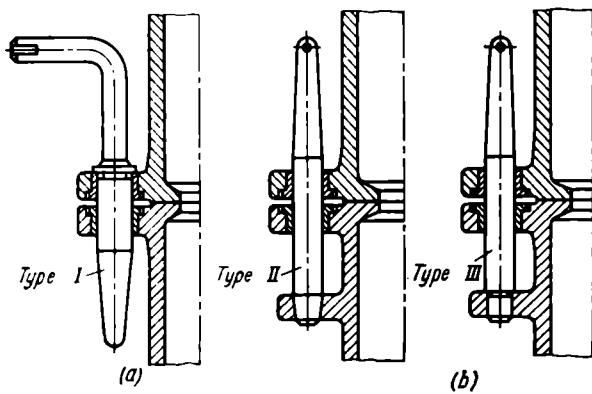


Fig. 44. Alignment of flask halves

After assembling the mold, the pins are withdrawn and used for centering other half-molds. In the second method (Fig. 44b) the pins are permanently secured in the drag, and the cope is placed on top of the drag so that the pins enter into the holes in the cope. The correct location is effected by pin bushes tightly fitted into the holes in the lugs and accurately polished on the inside. The pins are made of steel, grades 40 and 45, which are heat treated to obtain a surface hardness HRC of 40 to 45.

By the purpose they serve, pin bushes are divided into centering bushes (Fig. 45a) with round holes and guide bushes (Fig. 45b) with rectangular or elliptic holes. Bushes are made of grade 40 and 45 steels, and heat treated to a hardness of 45-50 HRC.

There are flasks for hand, machine, and automatic molding.

Flasks for hand molding must be as light as possible (about 30 kg without molding sand, and about 60 kg with the sand). The flasks of a larger mass need be handled with cranes. By volume, these crane-type flasks can be small (up to 250 dm³), medium-sized (up to 750 dm³), and large-sized (up to 1 500 dm³).

Flasks for machine and automatic molding are costly, high-precision devices. They must be rugged, accurate in dimensions and interchangeable. The size in the clear, the inside height of flasks, and also the dimensions and design of flask elements such as walls, trunnions, hand grips, pins, and bushes are standardized.

For transporting and assembling of molds, foundries often use *bottom plates* which are cast from secondary alloys and iron or, more rarely, welded from steel sheet. The plates are provided with holes for venting gases escaped from the molds. Small bottom plates have lugs (hand grips) and larger ones trunnions for crane handling.

4.2. HAND MOLDING

There are the following types of hand molding: floor, flask, sweep, skeleton pattern, strickle molding with gages, and core molding.

4.2.1. FLOOR MOLDING

This type of molding is generally adaptable to the piece or small-lot production of large castings. Molding is done in pits dug on the earth floor of the foundry; deep pits are laid out with brick and provided with gas-vented and gas-permeable mold beds.

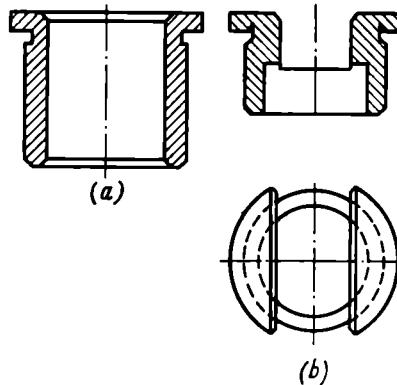


Fig. 45. Pin bushes

The beds can be permanent and occasional, depending on the mass and height of the pieces being cast. The first type is used for molding flat castings of small height, and the second type for large objects.

Floor molding has its shortcomings: (1) necessitates labor-consuming operations such as digging pits and preparing gas-vented mold beds; (2) calls for a large volume of manual work and employ-

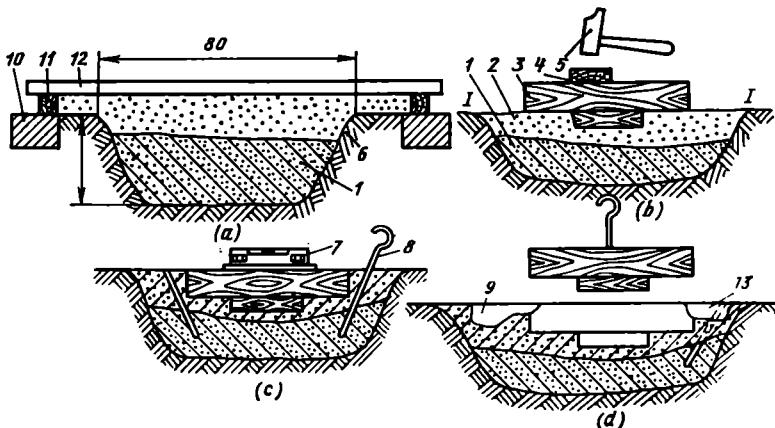


Fig. 46. Molding a disc in permanent bed of sand

ment of high-skilled molders; (3) endangers the health of personnel because of harmful dust, high temperature, and heavy sanitary conditions in general; (4) gives a small tonnage of sound castings per square meter of the molding floor area. The method is, however, simple and does not require equipment.

Molding in the permanent bed of sand. Fig. 46 gives an example of molding in schematic form of a disc in a permanent sand bed. After digging a pit 200 mm deep (Fig. 46a) in foundry floor 6 and filling it with backing sand 1, the molder places wooden bars 11 on two massive metal beams 10, verified for position with a spirit level throughout their length and relative to each other, and riddles facing sand 2 between the bars to a depth of 20-30 mm. He now smoothes out the sand with a straightedge 12, then takes the bars 11 aside, rams the sand with the same straightedge and trims it off level with plane I-I.

The molder then presses pattern 3 into the sand by striking gently on a wooden bar 4 with a mallet 5. He checks the horizontal position of the pattern face with a spirit level 7 (Fig. 46c).

After the molder has rammed the molding sand around the pattern and cut off the excess sand by the straightedge level with the pattern

face, he makes holes through the mold with a vent wire 8, so that gases evolved from the molten metal can escape freely, and then withdraws the pattern. To keep the mold from erosion by the stream of molten metal, the molder shapes a pouring cup 13 as shown in Fig. 46d. Then he cuts the gate connection from the cup to the cavity and, on the side opposite the cup, he makes an over-flow gate 9 (side channel).

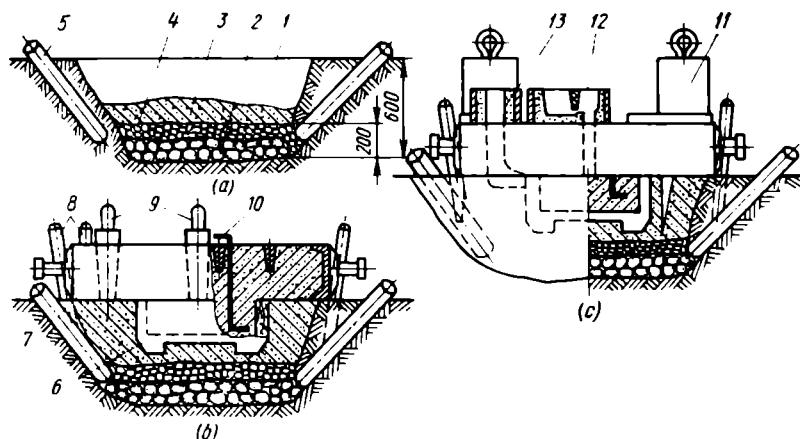


Fig. 47. Molding in vented pit

Molding in occasional (vented) pit. In this operation, the molder digs a molding pit (1) 300 to 500 mm deeper than the height of the pattern (Fig. 47a). He shovels coke or cinders 2 (the size of lumps being 50 to 70 mm) on the strongly compacted bottom of the pit to form a layer of 100 to 250 mm in thickness and rams the coke. Then he adds smaller-sized coke 4, slightly packs it and covers the bed with asbestos cloth. Further, he installs a gas vent pipe 5, with its upper end extending somewhat beyond the floor level, shovels molding sand 3 on the hard bed, places pattern 6 in position, rams the sand around it, makes vent holes (Fig. 47b), and trims off the sand to make the mold ready for installing cope flask 7 on top of it. The molder now sets up gate patterns 9 in the cope (to form the sprue, ingates, runner, and riser) and reinforcement rods 10, and then riddles the molding sand into the flask and rams it.

After lifting off the cope flask with a crane and withdrawing the pattern from the lower part of the mold, the molder finishes up the mold parts. Finally, the mold is closed, the right location of mold parts being secured with centering spikes 8, the weight 11 is placed on top of the mold, and sprue cup 12 and riser cup 13 are fixed in position as shown in Fig. 47c.

If the cope flask has protruding sand portions (projection cods), it is well to keep them in position with wire hooks, or rods, 10 (Fig. 47b). Coating the rod ends that face the pattern with liquid clay or lignin increases the adhesion of molding sand to the rods.

These wire reinforcement hooks are commonly installed in a cross-wise manner to give a higher strength to the mold. They are hanged on crosspieces (crossbars) or on rib edges of the flask. The distance between the hooks and the pattern must be equal to 70-100 mm.

For holding in place large and heavy projection cods located in the copes, one can use iron and steel reinforcement frames (grids) fastened to the cope half of the flask with bolts.

Projection cods must be well deformable, for the molten metal poured into the mold contracts during cooling and solidification. If the projection cod has low deformability, hot tears are likely to appear in the casting. That is why projection cods need be packed more gently than other parts of the mold. In dry-sand molding, projection cods are made hollow, or prepared from yieldable sands.

4.2.2. FLASK MOLDING

Flask molding (largely with split patterns) is the most widespread molding process. Flasks generally consist of two parts, the cope and the drag, or, rarely, of three or more parts (the intermediate sections being called cheeks). Molding in flasks produces castings more accurate in size than floor molding, because the centering pins and holes used here provide for a good location of the cope and drag.

Flask molding both with split and unsplit patterns can be performed in a variety of ways, depending on the shape of the pattern, its design, size, and the number of molds to be produced. In use are the methods of flask molding requiring parting-down (undercutting), with a pattern match, with a turnover green-sand ring core, with detachable parts, and others. The basic factors that determine the choice of the method for the production of a certain lot of castings of the given design are the required quality of products and the cost involved. Thus, parting-down molding or turnover molding permits in many cases dispensing with core boxes and cores in the piece production of castings. This lowers the cost of castings without affecting the quality. In machine molding, these methods do not commonly find application for they require manual work, which decreases labor productivity.

Cope-and-drag split pattern molding. First, a half-pattern 2 is fixed to a pattern plate 1 (Fig. 48a). The distance from the pattern to the flask wall must be 25-50 mm. Drag 3 is then placed on the plate, and the pattern is sprinkled over with a solution of kerosene and black oil (50% kerosene and 50% black oil) or dusted with a pattern powder (Fig. 48b). Next, the facing sand is riddled through

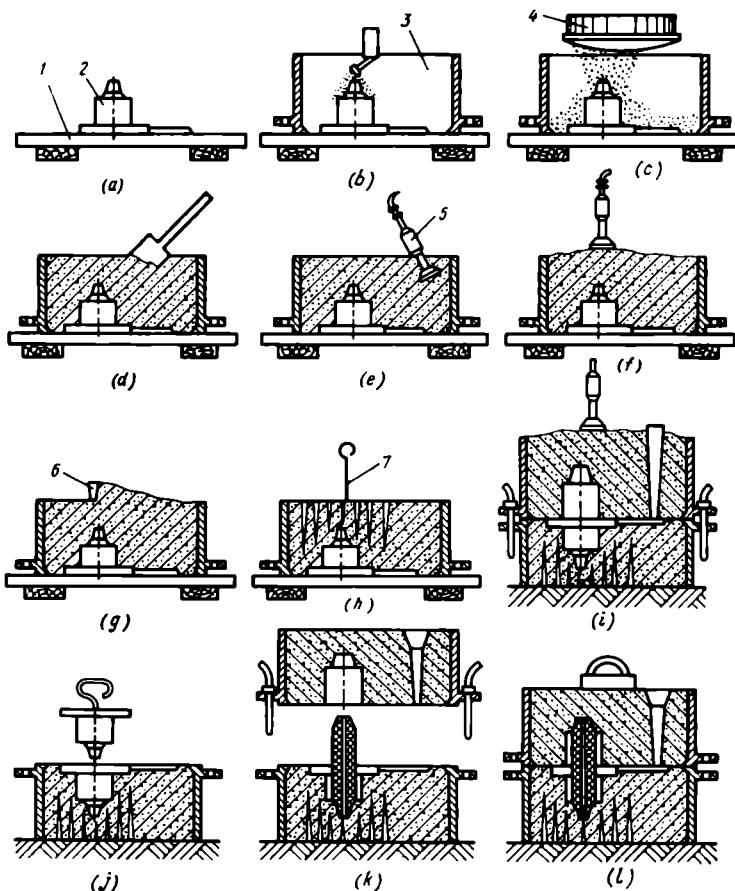


Fig. 48. Sequence of operations involved in the manufacture of a mold in a two-part flask

a sieve 4 on to the face of the pattern to form a layer of 15 to 30 mm (for small castings) or 30 to 40 mm (for large castings) (Fig. 48c).

In molding large castings with high and steep walls, the facing sand is riddled only on the horizontal surface of the pattern. The steep walls are coated with the same facing sand.

The backing sand is now riddled into the drag, and the sand is rammed (Fig. 48d). To provide for uniform density of the drag mold, the drag half of the flask is filled with the backing sand in layers (50 to 75 mm) and the sand is compacted with a rammer 5 (Fig. 48e, f). While compacting the sand, care must be taken not to strike hard on

the sand with the rammer because excessive ramming at the spot of impact may result in blowholes in the casting. Particular care must be exercised while ramming at the corners and near the flask walls.

After ramming, the excess of sand is cut off with a straightedge 6 level with the top of the box (Fig. 48g). The mold drag is now vented, that is, provided with vent holes by piercing through the mold, 10 to 15 mm short of the pattern, with a vent pin 7 (Fig. 48h). The drag with the pattern plate is then turned over and the second half-pattern is fixed to the plate.

To prevent the cope and drag halves from bonding together while ramming the cope, dry parting sand is sprinkled over the surface of the drag. This sand is blown off from the pattern surface by an air jet. The cope box is now placed on top of the drag, then facing sand is riddled on to the pattern, the sprue pattern is fixed in position, and backing sand is poured into the flask cope and rammed (Fig. 48i). Any excess of sand is brushed away and the cope is vented. This done, the cope is lifted off and set aside, the surface of the sand around the pattern is moistened with water, and the lifting screw is fitted into the threaded hole in the pattern (or draw spike is driven in). The pattern is rapped with a hammer by striking gently on the lifting screw, and then the pattern is withdrawn cautiously in the vertical direction (Fig. 48j). The sprue, riser, and gate pins are lifted up in the same manner. Small patterns are withdrawn manually and large ones with the crane.

Withdrawing the pattern from the mold is a responsible operation, which should be performed with much care not to cause damage to the mold. The pattern should not be rapped too hard, otherwise the casting will have an increased size and mass.

After removal of the pattern, the finishing operations follow. Trowels, spoons, slicks, and other tools are used to repair ruptured areas. Some portions of the mold are reinforced with sprigs. To prevent the molten metal from running out of the mold, notches are cut on the parting surface of the mold around the impression, 50 to 70 mm short of its edges. The parting surface of dry-sand molds is coated with a thin layer of clay to keep the metal from breaking through the joint during pouring. A finished green-sand mold is dusted before closing with powdered graphite or charcoal dust. In dry-sand molding, the mold surface is not dusted, but given a coat of wash. Coating is usually done after drying, when the mold is still hot. Sometimes molds are coated with washes two times, before and after drying. If cores are necessary, they are inserted in the cavities. The cope is then placed on the drag and the mold is closed (Fig. 48k, l).

Cope-and-drag unsplit pattern molding. As an example, consider the steps involved in casting a small lid using a wood unsplit pattern

(Fig. 49a). First the drag is made in the normal manner. For this the pattern is placed on the molding board along with the flask drag (Fig. 49b) to fill it with the molding sand. After sand ramming, the drag with the molding board is inverted, the board taken aside, the flask cope placed in position on top of the drag, the gate patterns fixed in the cope (Fig. 49c), and then the molding sand is riddled into the cope and rammed. Next the cope is lifted off and turned over to withdraw the patterns. The mold (Fig. 49d) is then finished up, closed and poured. Fig. 49e shows the casting with gates.

Molding with parting-down. This type of molding is applicable where an unsplit pattern has no surface suitable enough to place the pattern on the molding board (relative to the parting plane of the flask).

The pattern (Fig. 50a) bears on the board only by its projection, so that the molding sand flows into cavity 1 while ramming the drag. To withdraw the pattern, it is necessary to carve off the sand from the cavity with a trowel or sleeker (Fig. 50b). The surface of the cavity is then thoroughly smoothed over. This operation is called parting-down or coping-out. The plane of joint will be irregular (broken) in shape rather than flat.

The parting surface of the drag, the coping surface included, is then sprinkled over with the parting sand, or covered with paper in the case of deep parting-down. Next the flask cope (Fig. 50c) is placed on the drag and filled in with molding sand, which is then rammed. The mold is now taken apart to withdraw the pattern. Finally, the mold is closed by placing the cope on the drag and made ready for pouring (Fig. 50d). Fig. 50e shows the casting with the gating.

This type of molding is only applicable in casting a small number of parts using a given pattern.

Molding with a pattern match (Fig. 51). A pattern match can be prepared from ordinary molding sand, liquid glass-bonded sand, or gypsum. In casting a relatively large lot of pieces, use is made of a follow board which plays the part of a pattern match. This molding method eliminates the need for coping-out in the places of joint between the cope and drag.

Pattern 2 and the flask drag are placed on a follow board 1 (Fig. 51a), and then the mold drag is made in the normal manner. The drag with the plate is turned over and the follow board is removed (Fig. 51b), leaving the pattern in place. Next the flask cope is set up and the sand is rammed. The cope is then lifted off, the pattern withdrawn, and the mold closed for pouring (Fig. 51c).

Turnover molding (molding with a green-sand ring core). This type of molding finds use in piece production of small castings having recesses or cavities. The green-sand ring core here plays the part of a common core for forming the cavities.

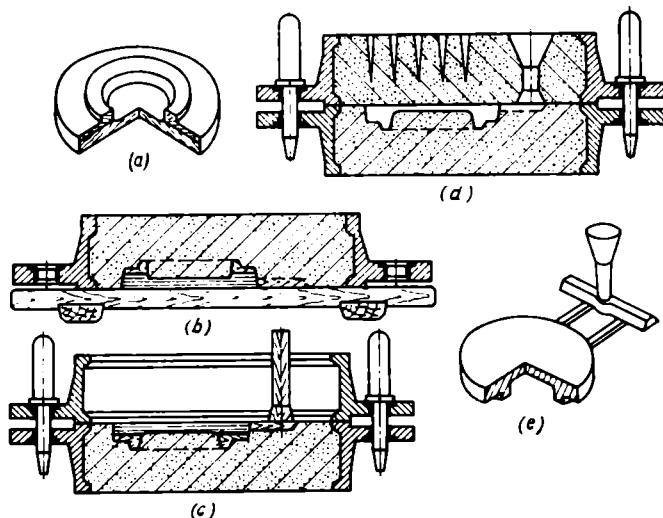


Fig. 49. Two-part flask molding with a single-piece pattern

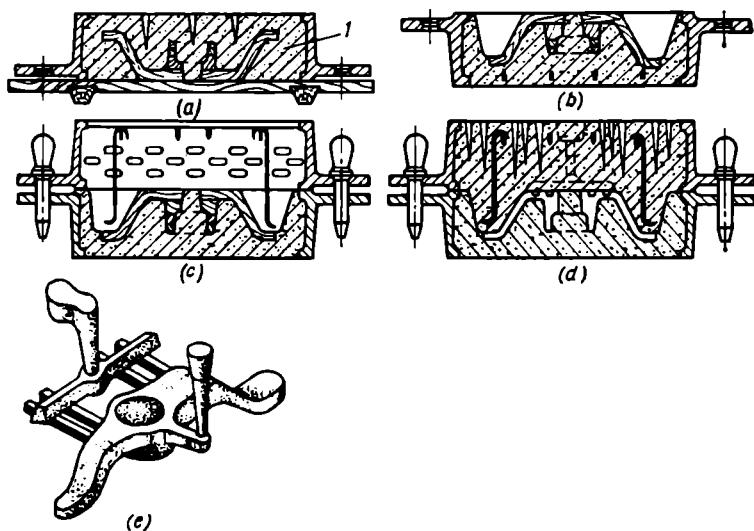


Fig. 50. Molding with parting-down

The pattern of a cable pulley (Fig. 52a) consists of two parts. One half 1 of the pattern is placed on a plate 2, and then a sprue pin 3 is set up on the hub of the pulley pattern. The flask cope is now fixed

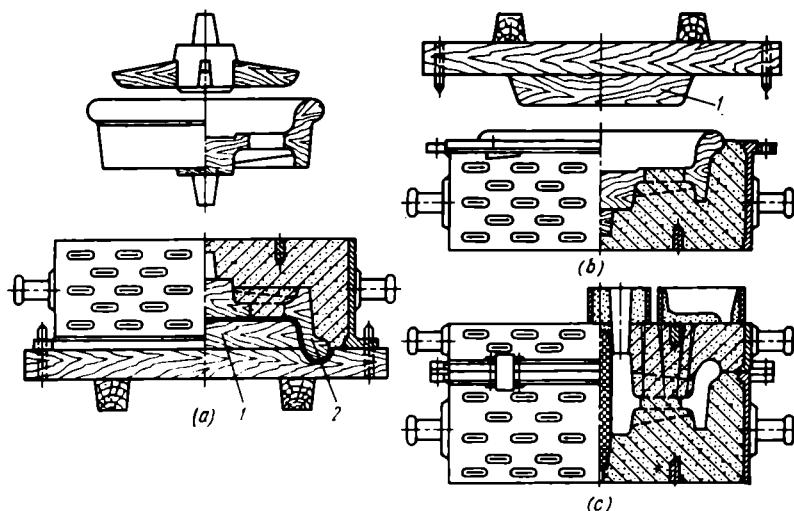


Fig. 51. Follow board molding

in position, filled up with molding sand and rammed (Fig. 52b). Next the sprue pin is withdrawn, the cope is covered with the plate and turned over. The pattern plate is then taken off.

To facilitate the removal of the pattern from the mold, the sand around the periphery of the pulley pattern is cut away along the line 4-9 (Fig. 52c). The surface so formed is sprinkled over with parting sand, then the second half-pattern 7 is placed on the first half-pattern, and the area is filled with molding sand to form a ring core 5. Surface 8 of the ring core is smoothed over with a trowel, sprayed with parting sand, and then a flask drag 10 (Fig. 52d) is placed on top of the cope, filled up with molding sand and rammed. Next the drag 10 is lifted off and put aside, the half-pattern is withdrawn from the cope, and the drag 10 is replaced. The mold is then inverted, the cope taken aside, the second half-pattern is drawn off the drag, and the loose sand blown off from the cavities by compressed air. Finally, a core 12 is set in and the mold is closed (Fig. 52e).

Multiple-part flask molding. This type of molding is practicable for casting pieces whose height is such that the two-part flask cannot accommodate the pattern. Also, some complex parts of a pattern call for several parting planes, otherwise it would be impossible to withdraw the pattern from the mold.

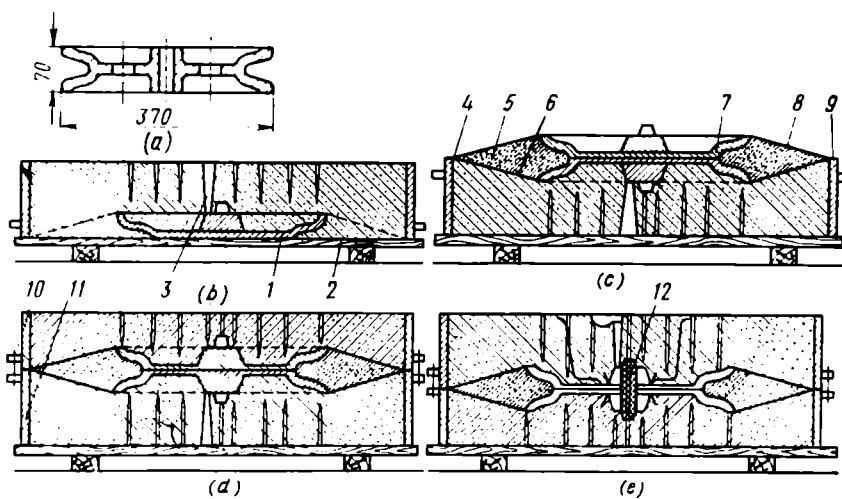


Fig. 52. Turnover molding

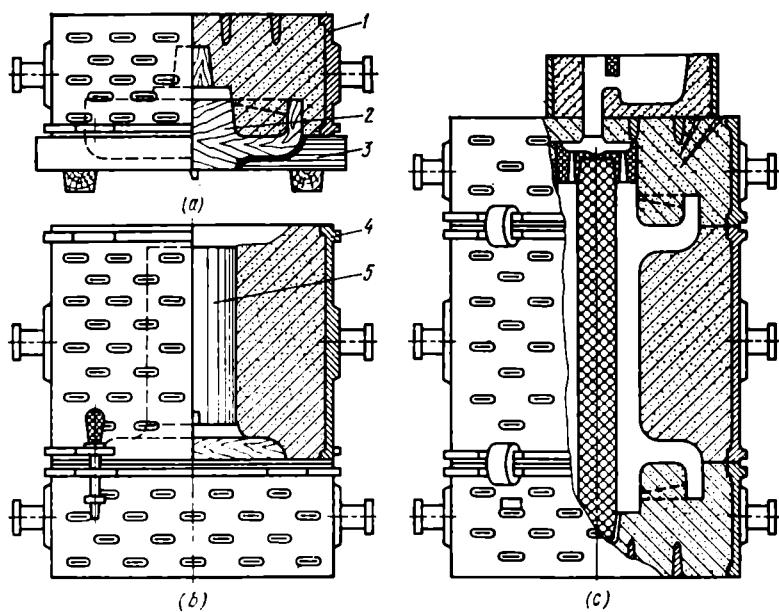


Fig. 53. Molding a drum in a three-part flask

Molding in three or more parts of the flask is performed in the same manner as in the two-part flask. As an example, Fig. 53 shows the process of molding a hoisting drum in a three-part flask. Molding begins with the preparation of a drag 1 (Fig. 53a). The split pattern used here has two loose parts 2 mounted on a follow board 3. After ramming, the drag is inverted, then a cylindrical part 5 of the pattern (Fig. 53b) is fixed to the drag pattern part. A cheek 4 is now placed on top of the drag, filled with sand and rammed. Next the upper detachable part of the pattern is set up in position, the flask cope is placed on the cheek and filled in with sand and rammed as usual. The mold is now taken apart to remove the pattern parts and insert the core, following which the mold is assembled for pouring (Fig. 53c).

4.2.3. TEMPLATE MOLDING

This molding method uses profiled templates, or sweeps, turning about a horizontal or vertical axis, or moving along a guide frame to form cavities in the molds. Sweeps either remove the compacted molding sand and thus shape up the cavities or smooth out the sand being laid on and rammed.

Sweep molding makes a suitable method largely for casting pieces which have the shape of solids of revolution (bushes, cylinders, tubes, pulleys, flywheels, and others), and also for forming the shape of castings by drawing the template (drawing strickle) along a guide frame. Sweep molding dispenses with patterns whose production takes much time and requires a large amount of wood. However, this method takes more time to form the mold than the method of molding with patterns. Moreover, sweep molding necessitates the employment of high-skilled labor. That is why the method finds fairly rare uses, largely for molding one or few castings.

Most popular are sweeping tackles with sweeps rotating about a vertically positioned metal spindle 1 set up in a socket 5 (Fig. 54).

The arm or holder 2 has slits for fastening sweep templates with bolts. The strickle arm 2 is fixed to the spindle with a clamping screw 3. The lock ring 4 (fixing collar) serves for setting the strickle arm in a definite position along the height of the spindle.

Consider the process of molding a ring with the aid of a template (Fig. 54a). First operations involve digging a pit and setting up the socket (spindle base) of the sweeping tackle, using the spirit level, to a certain depth below the mold, so that it cannot hinder the molding process (Fig. 54b). After compacting the molding sand around the socket and fitting the spindle into it, the molder fixes the collar, then hangs up the strickle arm and places on it the spirit level to check its horizontal position by rotating the arm around the spindle. The molder then fills the pit with molding sand and rams it. This done, he checks again the arm for horizontal position in the

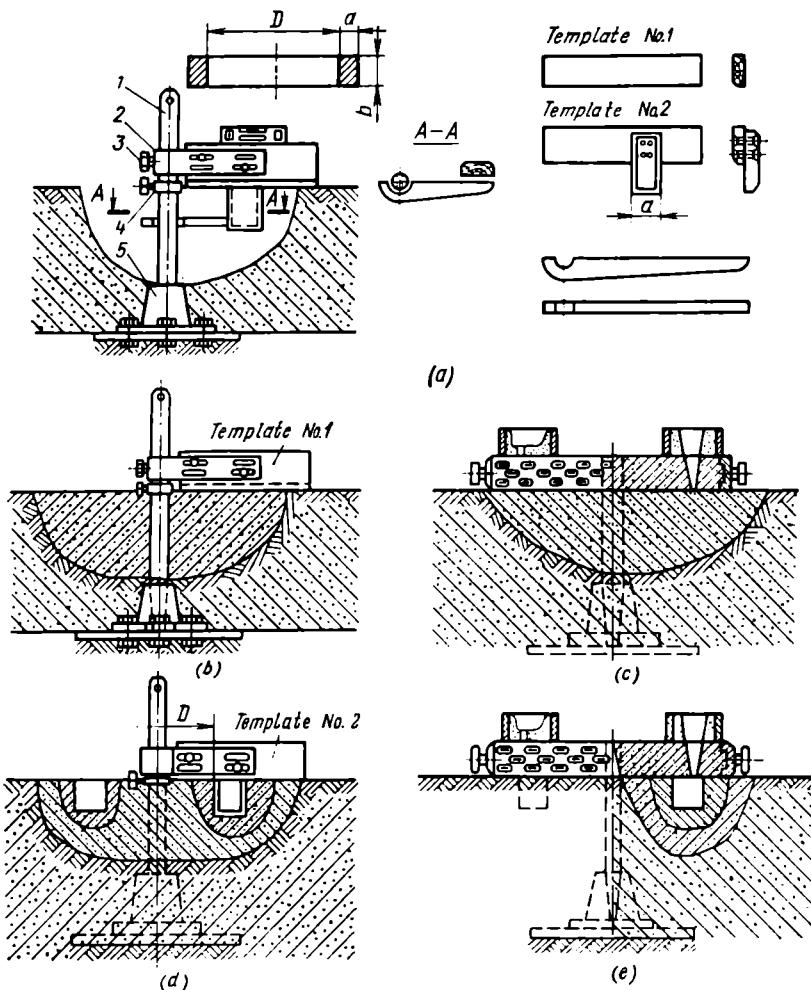


Fig. 54. Molding a ring with a sweeping tackle

same manner. Then he adds more sand, rams it and checks once more the position of the arm. After ramming the molding sand around the spindle base, the molder strikes off the sand level with the floor by means of template No. 1, sprinkles over the parting sand, then places the flask in position with a crane, fills it with the sand and rams it (Fig. 54c). Next he makes vent holes in the upper mold and then takes off the sprue and riser pins. The crane now lifts off the upper mold, the molder sets it aside and forms an annular

cavity in the pit for molding the ring. For this, he puts the collar and the arm with template No. 2 on the spindle and turns on the template to draw out the sand (Fig. 54d). The finished mold is shown in Fig. 54e.

Drawing strickle molding. The sand is drawn out by strickles (templates) pushed along a guide (frame). The cavity so formed can

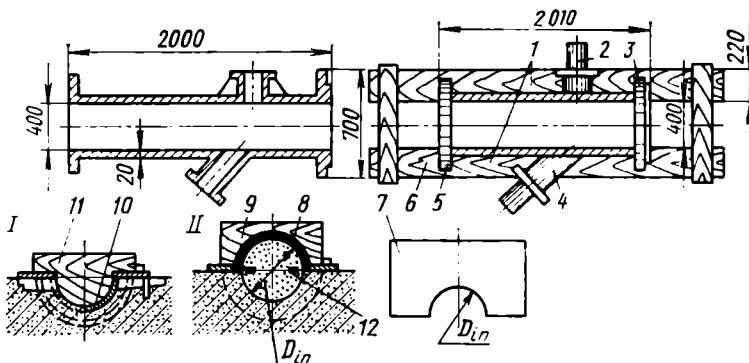


Fig. 55. Drawing strickle molding

also be used to mold a core, thus obviating the need for patterns and core boxes. This molding method is adaptable to the production of large-sized castings (connecting pipes, large-diameter pipe bends, and other pieces).

Figure 55 illustrates the scheme of molding a connecting pipe with flanges and two branches by using drawing strickles. The patterns of flanges, 3 and 5, and branches, 2 and 4, are made split along the parting line, each consisting of two pattern halves. A wooden guide or frame 6 has two detachable bars 1, which correspond to the thickness of the pipe body. The templates that form the core are drawn along the guide with bars 1, the other templates for the lower mold being pushed along the guide without the bars.

The molding operation comes to the following. The molder places the frame 6 with detachable bars 1 on the horizontal surface of the hard bed, presses back the lower halves of flange patterns into the sand, and draws out the sand with a template 11 (position I) to form an internal shape of the branch pipe. Then he coats the cavity of the 'core box' with paper and fills it with sand to mold the core. He shapes up the upper half of the core with a template 9 whose contours conform to the external surface of the pipe (position II). Next he fixes in position the patterns for flanges and pipe branches. Further, using a crane, he places the upper flask on top of the lower mold, fills the flask with molding sand, rams it and then removes the

upper mold and finishes it up. This done, the molder brings the core to the final size by removing from its upper half the sand layer 8 with a template 7, the layer thickness being equal to the thickness of the pipe wall.

The crane then lifts off the core by the pins of reinforcement grid 12 inserted into it during packing. The molder now finishes up the core to make it ready for dressing and drying. Then he cuts off a sand layer 10 (equal to the pipe wall thickness) from the surface of the lower mold, sets the cores for pipe branches (made in separate core boxes) into the mold, making sure that the core prints properly enter the core seats, and fixes them to the main core with pins. Finally, the mold is closed for pouring.

4.2.4. SKELETON PATTERN MOLDING

This molding method is the combination of molding with patterns and drawing strickles. It is employed rather rarely, mainly for casting large single pieces with variable cross sections. This method is applicable for forming both the mold and the core.

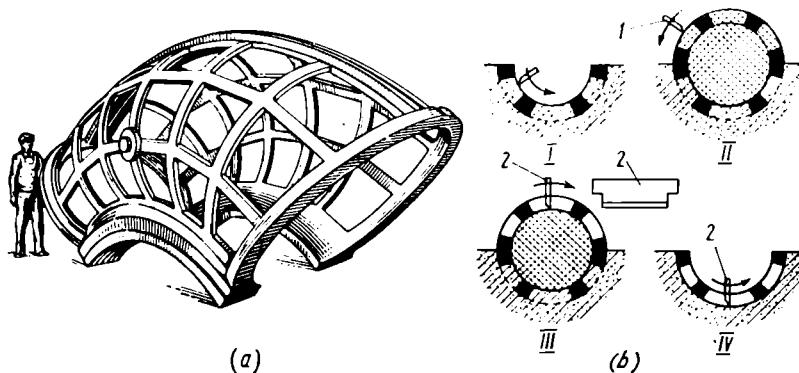


Fig. 56. Skeleton pattern molding

Figure 56a shows a skeleton pattern for one-sixth part of the built-up casing of a water turbine. The pattern is made from workpieces whose thickness is equal to the wall thickness of the casting.

One half of the skeleton pattern (position I) is bedded into the lower part of the mold (Fig. 56b), and a template 1 is then drawn along to take off the sand from the inside of the pattern and form the core box for molding the lower half of the core. The upper half of the core is made with the aid of the upper half of the pattern (position II). Now the flask is placed on the lower part of the mold, filled in with molding sand, rammed, and then lifted off and set aside.

Next the sand between the ribs of the pattern is cut off by drawing strickles 2 (position *III*). The upper half of the pattern and the core are then removed and the excess sand between the ribs of the half-pattern in the lower half of the mold is drawn out by the same strickles 2 (position *IV*). Further, the lower half of the pattern is withdrawn, the mold finished up, dried, and then assembled for pouring.

4.2.5. CORE MOLDING

This molding method finds use in the production of intricately shaped pieces, whose configuration makes it impossible to compact sand in pockets of the pattern, or when the pattern has a large number of loose parts. The casting mold is assembled of cores which can be made from different sand mixtures. Core molding finds application in the mass and large-lot production of castings. The main advantage of molding in cores is the possibility of dividing a complex mold into simple elements, cores.

Figure 57 gives an example of molding of a cylinder head in the core mold. Cores are made in core boxes and then assembled in mold jackets 1, 2 to construct the mold.

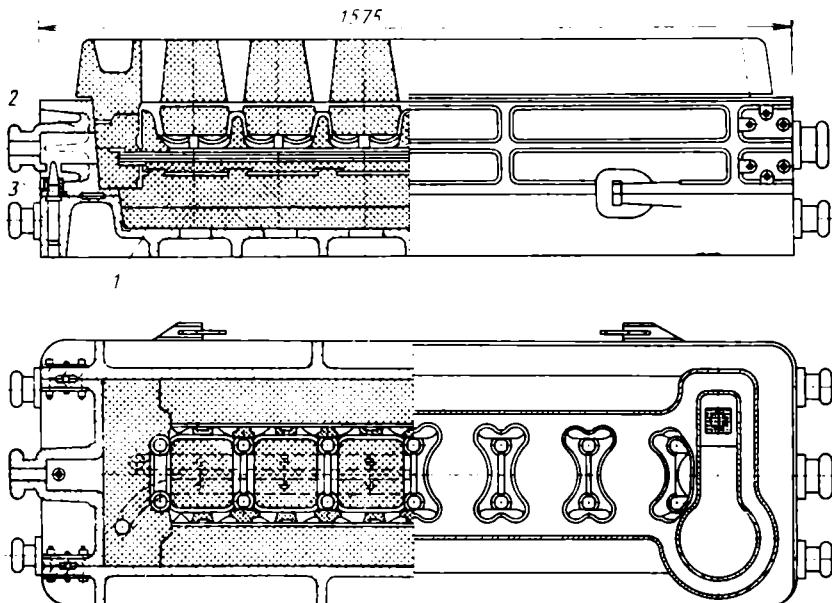


Fig. 57. Core mold for casting a thin-walled piece
1 and 2—jackets; 3—locating pin

4.2.6. CONSUMABLE PATTERN MOLDING

This full mold process is employed for casting large single pieces (5 to 20 t in mass), such as dies and other machine parts. The basic feature of the process lies in that the pattern made of expanded polystyrene need not be removed before pouring; while the molten metal is poured into the mold, the pattern immediately burns and evaporates under the heat of metal, leaving a cavity which is occupied by the melt (Fig. 58).

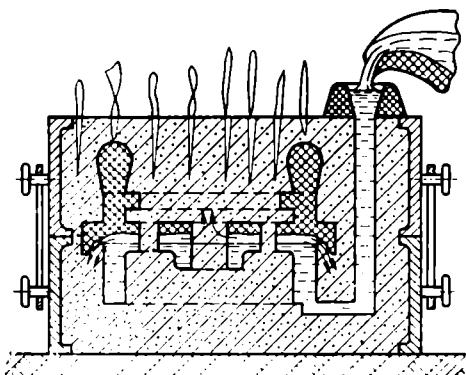


Fig. 58. Pouring a mold with a consumable pattern

The gasifiable pattern has a shape which is an exact replica of the casting, account being taken, of course, of the metal shrinkage and the stock left for machining. The process thus dispenses of the necessity of making cores to form cavities, holes, and protruding parts. The one-part mold has no parting line since there is no need here to withdraw the pattern. This is an obvious advantage, for the process does away with the need for labor- and time-consuming operations, increases the accuracy of castings, excludes the appearance of fins, and facilitates fettling operations for cutting off the gating.

To keep the metal from burning into the sand, the walls of a mold are coated with an antipenetration wash consisting of powdered zircon and the solution of polyvinyl butyral in spirit.

After drying of the wash, the mold is set in the flask and furnished with necessary gating elements. The bottom gating practiced here enables consecutive burning of the pattern; the gaseous products of decomposition disperse into the sand mold through the gap formed between the melt surface and the surface of pattern decomposition (Fig. 58). The materials used for the preparation of the mold are quick-hardening sand mixtures bonded with liquid glass, liquid self-curing mixtures, and cold-curing mixtures. In forming large

molds, the sand is compacted with pneumatic rammers, care being taken not to damage the mold since it has low strength.

Molds with expendable patterns are made without overflow gates or open risers to exclude the escape of gases and soot into the atmosphere. Pursuing the same goal, foundries employ the method of metal pouring combined with the simultaneous supply of CO_2 into the mold, or ejection and after-burning of carbon dioxide vapors and gases (products of pattern decomposition), which greatly decreases the amount of soot escaping into the atmosphere. All the same, the shops engaged in pouring the molds with gasifiable patterns should be provided with good exhaust ventilation.

4.2.7. PRODUCTION OF MOLDS FROM QUICK-HARDENING SAND MIXTURES

Molds produced from quick-hardening sand mixtures having liquid glass as a binder find use in the manufacture of castings from iron, steel, and nonferrous alloys up to 40 000 kg in mass.

The process of molding with these sand mixtures is in the main the same as with conventional sand mixtures.

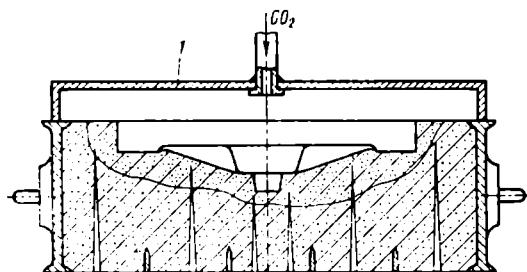


Fig. 59. Drying a liquid glass-bonded sand mold by carbon dioxide

The pattern is given a uniform coat of the quick-hardening sand 50 to 70 mm in thickness, and then the half-flask is filled with backing sand, and the half-mold is packed. Next the half-mold together with the pattern plate and pattern is turned over, the pattern plate lifted off, and the pattern removed. The half-mold is then covered with a hood 1 (Fig. 59) made of thin steel sheet or plywood.

Carbon dioxide supplied under the hood that covers the half-mold enables a fast and uniform hardening of the sand, because it causes decomposition of sodium silicate, formation of sodium carbonate and isolation of silica. Silicon dioxide, SiO_2 , takes up water and forms silica gel which bonds sand grains together and imparts strength to the mixture.

The amount of carbon dioxide expended for 1 ton of small castings (on average, 100 kg each) is 10 kg; for medium-size castings (on average, 600 kg each), it is equal to 3 kg. The time of blowing the gas through the molds of an area of 0.5 to 8.0 m² comes to 8 min at a gas pressure of 2 or 3 kgf cm⁻² (0.2 or 0.3 MN m⁻²).

The use of liquid glass-bonded fast-curing sand mixtures excludes drying of medium-sized and large molds and raises the output per man-hour. This method is most widespread in the batch and piece production of castings.

4.3. MACHINE MOLDING

This molding method is largely applicable in batch and mass production. Machine molding is also possible to apply in small-lot and piece production when using quick-change pattern sets.

Compared to hand molding, machine molding has the following advantages. It enables higher output, increased accuracy of castings and thus smaller machining allowances, and eliminates hard work of molders owing to the mechanization of laborious operations of sand ramming and pattern removal.

Machine molding provides for better dimensional accuracy of castings because it employs more accurate and less tapered patterns,

dispenses with rapping and uses instead vibrators in removing the patterns, and secures more exact location of the cope and drag.

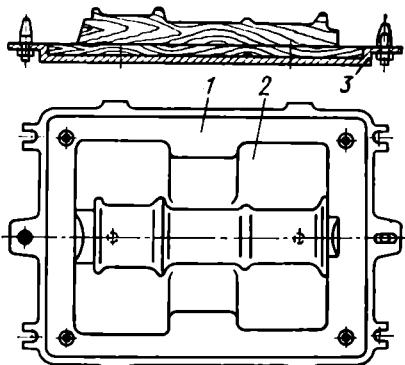


Fig. 60. Metal pattern plate with a cliché plate

Single-sided metal pattern plates with metal patterns (see Fig. 21) find use in mass and large-lot production, and quick-change pattern sets in piece production.

Metal pattern plates with wooden inserts (Fig. 60) are adaptable to small-lot production. Wooden insert 1 (cliché plate) with pattern 2 is fastened to a metal plate 3 with bolts. The composite pattern plates

4.3.1. SOME FEATURES OF MACHINE MOLDING

Molding equipment. Machine molding mainly uses two-part flasks, and the mold thus consists here of the cope and drag, the exception being stack molding and slip-flask (removable flask) molding.

(cliché pattern plates), as shown in Fig. 61, are also suitable for use in the batch production of castings. Such plates allow for a fast change of reversible pattern plates and complete utilization of the mold area owing to the simultaneous molding of parts varying in shape and mass.

Master pattern plates (Fig. 62) are employed in piece and small-lot production. They have holes for setting up and fixing in position half-patterns. The letter-and-number code designation for each hole helps mount the patterns on the plate. The longitudinal section of the mold shows the way how letter-labelled coordinates for drag-half pattern 1 and cope-half pattern 2 must be brought into coincidence. The longitudinal axes of the casting are made coincident by shifting the half-patterns 1 and 2 from the symmetry axis 5 of the plate for a distance of one step of the grid in the mutually opposite directions. Here the same point is labelled by the indexes B6 (on plate 3) and B4 (on plate 4). The axes of the gate channel are shifted in the same manner.

Production process. Machine molding involves a number of operations. *Basic operations* such as ramming the molding sand in the flask and removing the pattern from the mold determine the quality of the casting: the presence of contaminants, geometrical accuracy, surface roughness, and so forth. These operations are performed by molding machine mechanisms, which results in the improved quality of molds and castings. *Auxiliary and handling operations* are carried out by the auxiliary and conveying mechanisms of molding machines. These operations include mounting the flask on the machine, blowing over the pattern plate and coating it with a parting compound, pouring the molding sand into the flask, transporting, and assembling the mold.

As regards the degree of mechanization of molding operations, it is usual to differentiate between mechanized molding, where the operator controls the mechanisms executing basic, auxiliary, and handling operations, and automatic molding, where the machine itself exercises control over the operation of mechanisms.

The most laborious and important operations are ramming and pattern removal. There are several methods of machine ramming: by squeezing, squeezing and vibration, jolting, jolting and squeezing, sand blowing, blowing and squeezing, and so on.

Each of the methods has its own rational field of application, depending on the pattern shape, mold size, sand properties, and nature of production. The main methods of sand ramming are considered below.

The main feature of machine molding is the short duration of basic and auxiliary operations. This ensures a high output per man-hour. The machine molding process usually excludes finishing operations such as venting of the molds and coping-out, which necessitate

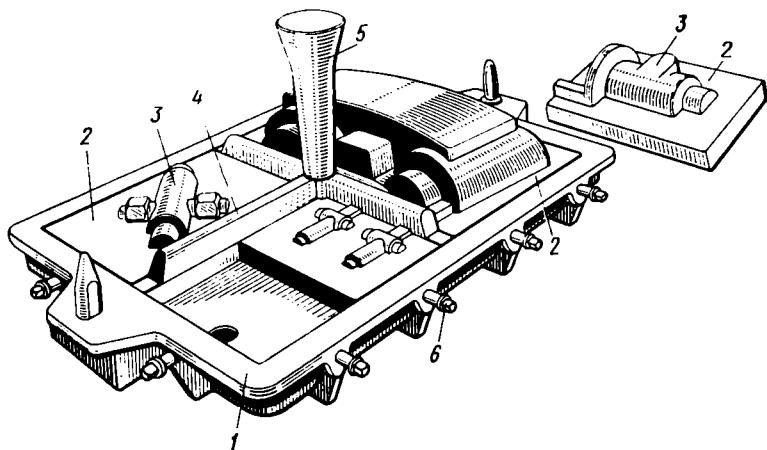


Fig. 61. Cliche pattern plate

1—base plate; 2—detachable cliche plate; 3—pattern; 4—center runner pattern;
5—sprue pattern; 6—stop screws

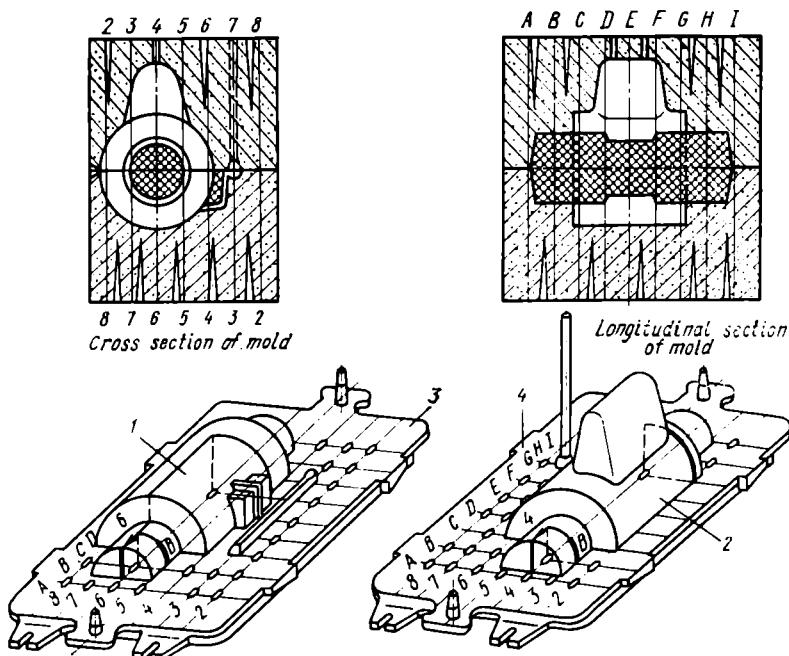


Fig. 62. Master pattern plate

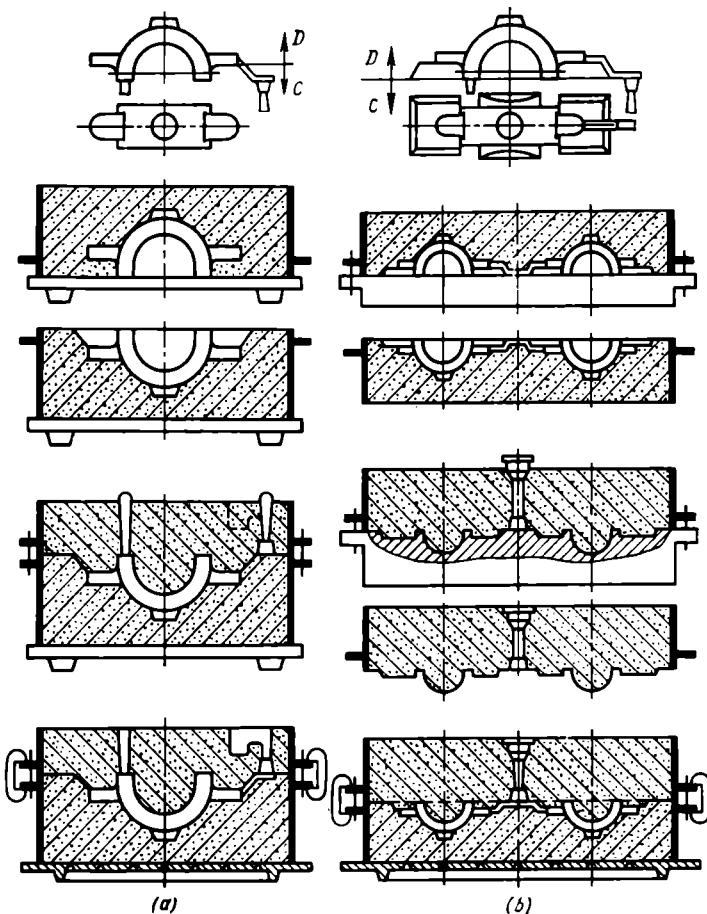


Fig. 63. Schemes of hand (a) and machine (b) molding stages involved in the manufacture of a mold for casting a bearing cap

manual work. The process uses patterns without loose pieces and produces molds without ring cores. This is particularly the case in the large-lot and mass production of castings. These operations would decrease the output and effectiveness of the machine.

The use of facing and backing sands also decreases the productive capacity of equipment, for which reason the machine molding process, especially in large-lot and mass production, employs unit sands of high strength and gas permeability.

Figure 63 gives the schemes of preparing the mold for casting a bearing cap by resorting to hand molding with coping-out and to

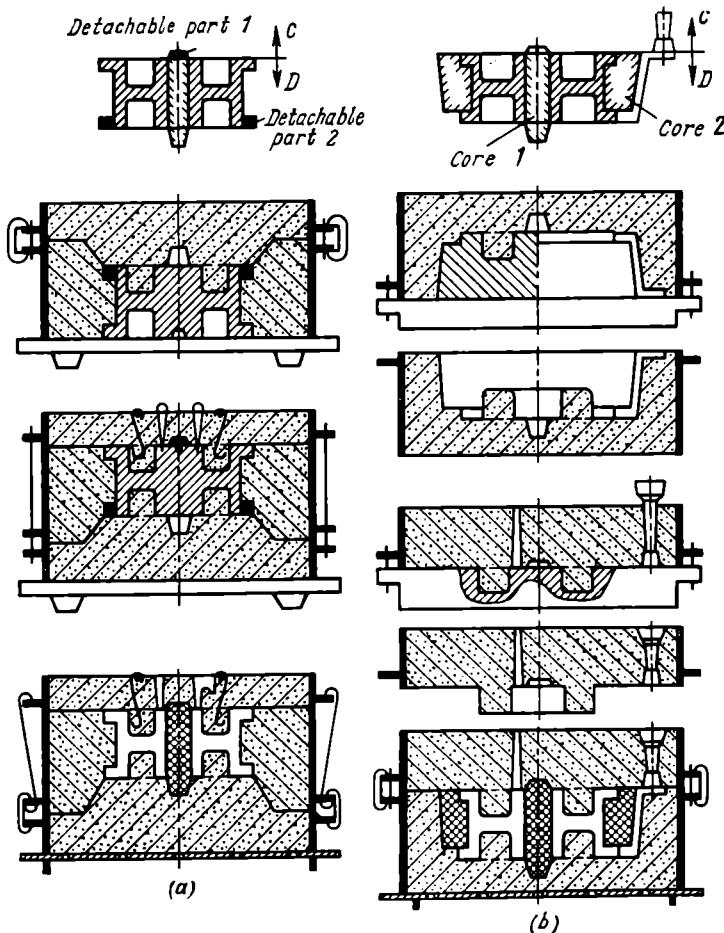


Fig. 64. Schemes of hand (a) and machine (b) molding stages in the manufacture of a mold for casting a sheave

machine molding. The use of the follow board eliminates the coping-out operation in machine molding. Also, in machine molding, the patterns form gating channels and the spring gate stick forms the sprue with the pouring cup. This does away with the need for cutting gating connections in the mold by hand.

Figure 64 shows the schemes of making the mold for casting a sheave, using hand molding and machine molding. In hand molding, the pattern has detachable parts 1 and 2 molded with coping-out in a three-part flask. The ring cores are reinforced with metal pins, and the gating system is cut by hand. In machine molding, the sheave

groove is formed by core 2. Molding is performed in a two-part flask, using a follow board. A high strength of molding sand eliminates the need for reinforcement pins. The pattern fixed to the pattern plate and the spring gate stick serve to form the gating system.

However, in the batch production of molds (especially moderate-sized and large-sized molds), the machine molding process includes manual operations for finishing up the molds and resorts to detachable pattern pieces and also to facing and backing sands. This is due to the fact that the use of rather expensive unit sands for the entire volume of a large mold adds to its cost and lowers the effectiveness of the process in general. It is economically justifiable to make molds with facing sands. The use of a small number of simple loose pattern pieces decreases somewhat the output, but, from the standpoint of economy, can render the process more effective than when machine molding makes use of highly expensive core boxes and cores.

In mass production and automatic molding, it is common practice to form molds only from unit molding sands and totally exclude handwork necessary to repair and finish up the mold. This enables a more effective utilization of equipment capacity and improves the quality of castings.

4.3.2. MACHINE RAMMING

In machine molding, the following methods of compacting molding sands find most widespread use: jolting, squeezing, jolting and squeezing, sand blowing and squeezing, and sand throwing (slinging).

Squeezing. There are two ways of consolidating the sand by squeezing: top and bottom squeezing. In a schematic diagram of the top squeezer machine shown in Fig. 65a, the pattern plate with a pattern 2 is clamped on a work table 1. Flask 3 with a filling frame 4 is then placed on the pattern plate. Stationary squeeze head 6 with a packing block 5 (platen) is located above the sand frame 4. The height of the platen 5 is equal to the height h of the sand frame. As the table moves up, the squeeze head remains stationary, and the platen enters the frame and compacts the sand down to the upper edges of the flask. In some squeezer machines, the squeeze head with the platen moves down to compact the sand, while the table remains motionless.

In the schematic diagram of a bottom squeezer machine (Fig. 65b), table 1 with a pattern plate and pattern 2 moves vertically relative to a stationary frame 5. Before squeezing, the pattern 2 with the pattern plate is located below the upper edges of frame 5 which supports a flask 3. The frame contains an extra layer of sand, equal to the volume V , which makes up for the decreased volume of sand during squeezing. The volume V is determined by the height H of sand layer and the flask area. In the procedure, as the flask is filled

with sand, a squeeze head 4 is brought against the top of the flask. Next the table is pushed up by the lift mechanism, and the sand is squeezed out from the frame 5 into the flask by the pattern plate 6 fastened to the machine table. The travel of the table must be equal to the height H of sand layer so that at the end of the squeeze stroke the plane of the pattern plate can be in line with the parting plane of the flask.

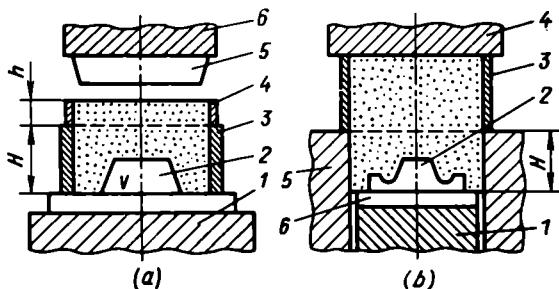


Fig. 65. Schemes of top and bottom squeezing

The method of top squeezing and top presqueezing of molds is much more popular than bottom squeezing. In bottom squeezer machines the sand gets down into the gap between the table 1 and frame 5 and causes quick wear of rubbing parts. Besides, it is difficult to readjust these machines for another flask size.

It is found that the densities produced by a squeeze molding machine decrease away from the packing platen. This is due to the friction of sand against the flask walls. The friction also accounts for the lower density of the mold at the flask walls than in its center. The higher the flask, the less uniform is the density of sand over the flask height. Thus, as the height of the flask increases, the average density of sand decreases and the nonuniformity of packing grows.

The value of density and the character of density distribution over the bulk of the casting mold depend on the ratio between the height H of the mold and its minimum size B_{\min} in the plane. At H/B_{\min} equal to about 1 to 1.25, the density in the center of the mold is found to be uniform. As this ratio grows, the nonuniformity in density distribution grows too. It is thus more advantageous to squeeze sand in shallow flasks.

The above description relates to sand packing in flasks without patterns. If the flask has patterns, then the minimum distance between the pattern and flask upper edges is taken as a measure by which one can judge of density distribution.

In the course of ramming the sand in the flask with a pattern, the volumes of sand shift, or flow, one relative to the other.

In compacting sand with a flat platen (Fig. 66), the squeezing pressure first acts on the sand in zone I above the pattern. As the sand comes to the state of limit equilibrium, it begins to flow to the flask walls, into zones II. The pressure of the platen then disturbs the state of equilibrium in these zones, and the sand starts moving into zones III. The sand goes on shifting until the action of pressure applied to the platen ceases. But since the patterns of sand flow in the zones are different, the densities in each will not be the same. The greatest density of sand will be in zone I above the pattern, and the lowest density in zones II and particularly in zones III. The mold so packed may result in a defective casting because excessive compaction and thus lowered gas permeability of zone I may cause the formation of blowholes, and insufficient compaction of zones III may lead to deformation of the mold under the pressure of metal and thus to mold erosion and bulging of the casting. So, the task of greatest importance in machine molding is to produce molds of uniform density. The density of noncompacted molding sand is usually equal to 1 to 1.1 g cm^{-3} . The compacted sand has a density of 1.4 to 1.6 g cm^{-3} .

For obtaining molds of uniform density, foundries resort to a variety of measures: use machines of increased squeezing pressure, combine the process of squeezing with vibration, utilize special molding sands, and work out various technological approaches, among which are squeezing with shaped pressure squeeze boards, multiple-plunger squeezing, and squeezing with rubber diaphragms.

At low and medium pressures of sand compaction, coming to 490–588 kPa ($5\text{--}6 \text{ kgf cm}^{-2}$), it is common practice to use profiled platens whose ridges are sized to conform to the size of patterns (Fig. 67a, b). The platen so shaped first compacts the sand in zones II and then in zone I, which ensures more uniform density over the bulk of the mold and improves its quality. This approach comes handy in preparing low-height molds.

During squeezing, the vibrator shakes the flask and thus decreases the friction of sand against the flask walls owing to the gap formed between the sand and walls.

In a multiple-plunger squeezer machine (Fig. 67c), the communicating cavities of cylinders form connecting vessels filled with pressure fluid. During squeezing, the table with the pattern plate moves up

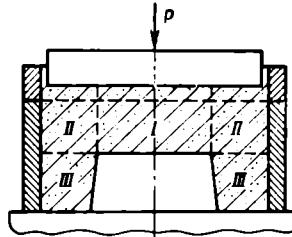


Fig. 66. Scheme of flow of sand in the process of its compaction in the flask with a pattern

toward the stationary platen. The degree of resistance the sand offers to the movement of individual plungers is different, so that the penetration depth of plungers varies with the sand resistance. In this procedure, the liquid flows over from the cavity of one cylinder to others and the pressure remains invariable. This ensures the flow of sand and uniform distribution of sand density over the entire volume. This platen is called passive because it is stationary.

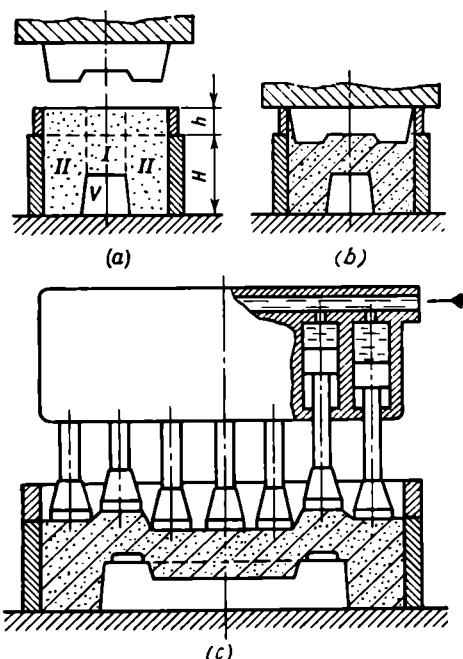


Fig. 67. Scheme of mold ramming by squeezing, using a shaped pressure squeeze board (a,b) and multiple-plunger platen (c)

Fluid flows into the cylinders at a constant pressure, and plungers squeeze the sand independent of one another. This secures better conditions for liquid overflow and more uniform sand density over the bulk of the mold.

Multiple-plunger packing platens produce uniform sand densities and therefore enjoy wide use in modern squeezer machines.

The methods for determining the density of molding sand in various portions of the mold are rather laborious. They are only appropriate for special purposes (researches into the process of compaction).

In foundry conditions, laboratories use a mold-hardness tester (Fig. 68) for the measurement of surface hardness of the mold. This measurement serves as a substitute for sand density measurement. The tester with its outwardly projecting ball is placed on the surface of the mold. The ball 10 mm in diameter penetrates into the sand only to a certain depth depending on the mold hardness. Inside the device, the ball is constantly acted upon by the spring pressure equal to 9.81 N (1 kgf), so the penetration depth of the ball only depends on the surface hardness of the mold. Movement of the ball is transmitted to the turning pointer of the device. The tester scale bears

100 graduation marks. As the hardness of sand grows, the pointer sets at a larger figure. The hardness of a sand mold, as read from the hardness tester scale, ranges from 25 to 30, 50 to 60, 70 to 80, and 85 to 90 units in weak, moderately strong, strong, and very strong ramming, respectively.

Jolting. This method of sand compaction uses jolt molding machines. The procedure comes to the following. First the pattern plate is fixed to the work table of the machine and then the flask is placed on the plate and filled with molding sand. Next the table is lifted up to a height of 50-60 mm and then allowed to drop freely to strike against the machine platen or pads. The speed of the table, pattern plate, and the flask becomes equal to zero, while the sand goes on moving and thus compacts: its kinetic energy converts into the energy of impact which packs the sand. The table then returns to the upper position, and the next impact follows. The cycle is repeated several times.

This method does not secure uniform density of the sand in the mold. The densities are greatest in the layers next to the pattern plate and lowest near the top of the mold, because in the course of impact on the lower layer. That is why the upper layers have a density practically equal to the bulk density of the sand, which is far from being enough to ensure the required strength of the mold. The compaction is most nonuniform near the corners of the pattern (Fig. 69).

The jolting method is suitable for compaction of a molding sand of any green strength. What deserves particular mentioning is the fact that jolting makes an appropriate method for ramming sands in high flasks. These advantages account for the widespread application of jolt molding machines in the batch and mass production of small, medium-sized, and large castings.

The shortcomings of the method are the high level of noise produced by the jolt machines in operation and considerable loads on the foundation.

The jolt squeeze method is free of the basic limitation of the jolting method—weak compaction near the top of the mold. The method combines jolting with squeezing, which gives the molds a high and uniform density and increased strength and enables the production of accurate castings of high quality. Jolt squeeze machines now find most widespread use in the foundry practice.

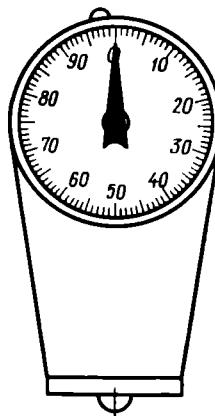


Fig. 68. Mold-hardness tester

Air impact compaction. Fig. 70 shows the schematic diagram of an air impact molding machine. A highly rugged and strong flask 2 mounted on the pattern plate 1 with a pattern is filled with mold-

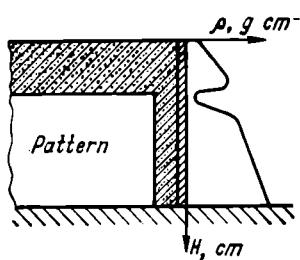


Fig. 69. Sand density distribution over the height of the mold with a pattern during compaction by jolting

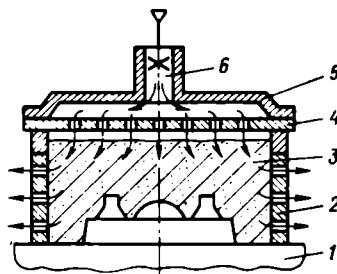


Fig. 70. Scheme of sand compaction by air impact

ing sand 3 and covered with a plate-diffuser 4 having a large number of holes. Then an air impact head 5 with a starting valve 6 is set on top of the plate. The head, plate, and flask are tightly clamped together by a special mechanism.

As the valve is turned open, the air compressed to $4.9\text{-}7.85 \text{ MPa}$ ($50\text{-}80 \text{ kgf cm}^{-2}$) forces its way fast through the plate holes into the flask and compacts the sand by virtue of its dynamic action and filtration through the pores. The air escapes into the atmosphere through vent holes.

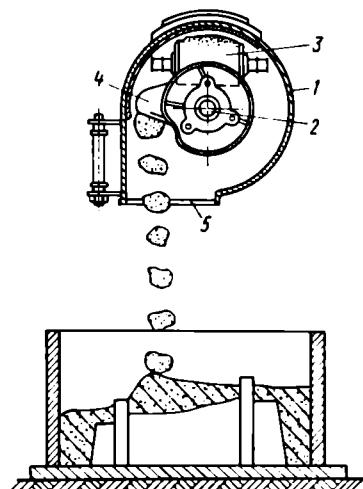
The machine produces molds of high and uniform density. The point in favour of such a machine is the absence of moving parts (plungers, platens, diaphragms, and others) which come in contact with the sand. The process of compaction takes a very little time, so that it enables rather high production. This method is finding ever increasing use in lot production for the manufacture of medium-size and large molds which require flasks furnished with crossbars. The advantages of the method can make it adaptable to mass production too.

Fig. 71. Principle of sand slinger operation

Sand slinging. The basic operating unit of a sand slinger is an impeller head (Fig. 71). The head consists of a housing 1 accommoda-

ture of medium-size and large molds which require flasks furnished with crossbars. The advantages of the method can make it adaptable to mass production too.

Sand slinging. The basic operating unit of a sand slinger is an impeller head (Fig. 71). The head consists of a housing 1 accommoda-



ting a rotor with a blade 4, fitted on to a shaft 2 rotating at a speed of 1 450 rpm. A belt conveyer 3 delivers molding sand inside the sand slinger head through an opening in the end face of the housing. The blade picks up the sand in portions and throws it at a high speed, up to $16\text{--}30 \text{ m s}^{-1}$, through an outlet 5 in a practically continuous stream. As they fall into the flask, the portions of molding sand strike against the pattern and the pattern plate and are compacted as a result of the kinetic energy of impact. To secure the required compaction of molding sand, it is necessary to shift the head gradually over the flask, which calls for certain skill of the operator.

Unlike jolt molding and squeezer machines, a sand slinger performs at once two operations: delivers molding sand into the flask and compacts it. The productive capacity of a sand slinger is very high, 3 to 50 m^3 rammed sand per hour. It is therefore advisable to use a sand slinger for ramming large and extra large molds in flasks over $700 \times 600 \text{ mm}$ in the clear and over 150 mm in height.

Sand slingers come in two types, stationary and mobile. Stationary sand slingers are mounted on supports so as to enable a maximum utilization of the service zone. Mobile sand slingers travel along the shop bay on rails and ram the sand in flasks set up on the way. A sand slinger is usually automatically controlled and attended as a rule by one operator.

4.3.3. PRODUCTION OF MOLDS ON MOLDING MACHINES AND AUTOMATIC MOLDING LINES

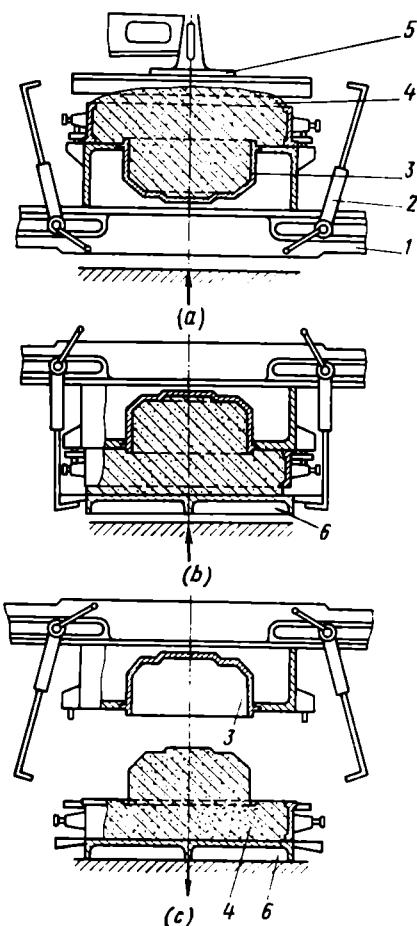
Various molding machines and automatic molding lines are available to foundries, the choice of equipment being dependent on the mass, size, and shape of pieces cast, the kind of alloy, and the character of production (batch or mass production).

Jolt squeeze machines find use in the preparation of molds for casting batches of small-size pieces from iron, steel, and nonferrous alloys.

Production of molds for casting batches of medium-size castings. The molding machines used here are jolters or jolt squeezers. The design of machine chosen for the purpose must be such that after removal of the pattern the cope and the drag should take the positions convenient enough to insert cores and assemble the mold.

For molding drags, foundries make use of jolt squeeze turnover-draw molding machines (Fig. 72). The machine of this type has a squeeze cylinder built into the bed. The squeeze piston serves at the same time as the cylinder of a jolting machine. In operation, the squeeze piston moves up and connects the squeezing mechanism to the air line. The compressed air goes in under the jolting piston and initiates ramming of the drag by jolting (Fig. 72a). Further, the excess sand is cut off with a scraper 5, a plate 6 is placed on the flask

drag 4, and then the plate and the drag are fastened to the machine table 1 with pneumatic clamps 2. The table with the drag is now turned over by a special mechanism and the sand is compressed by the squeezing mechanism (Fig. 72b).



Next the pneumatic clamps automatically release the flask drag from the plate and the turnover table with the pattern 3 returns to the original position. The finished drag is then pushed from the work table on to the roller conveyer for assembling.

For molding cores in the conditions of batch production, foundries use jolt pattern-draw molding machines (Fig. 73). Pattern plate 6 with a pattern 2 is clamped on the work table of the machine. The sand in a flask cope 3 is compacted by jolting and then the mold cope 4 (Fig. 73a) is squeezed by a platen 5 (Fig. 73b). After squeezing, the table 1 (Fig. 73c) with the pattern plate 6 and pattern 2 goes down, while the cope remains on a stripping plate 7. The cope 4 is then taken off the plate 7 and conveyed for assembling.

Machine molding does not exclude altogether hand operations, which lower the output and affect the conditions of labor, because the operator must stand by permanently in attending the machine. In the conditions of lot production, machine molding is gradually giving way to automatic molding which uses quick-change pattern plates.

Fig. 72. Stages of manufacture of a mold drag on a jolt squeeze turnover-draw machine

Molding in jolt rollover machines. These machines find use in the lot production of castings. They produce large and high half-molds. The sand in flasks is compacted only by jolting. Upper layers of sand are packed by hand pneumatic rammers. The flasks used here measure up to $3\ 000 \times 2\ 000 \times 600$ mm. The machines are also suitable for molding large cores.

Figure 74 shows the principle of operation of a jolt rollover machine, which consists of three basic units: a jolting mechanism, rollover table, and a mold-receiving and pattern-stripping mechanism. The flask is placed on the pattern plate with a pattern (Fig. 74a), which is blown off by compressed air and sprinkled over with parting sand. The flask is then filled with molding sand charged from the hopper. The jolting mechanism is now switched on to ram the sand. The upper layers of the mold are then packed using pneumatic rammers. Next a plate is set on top of the flask and fastened to the table with pneumatic clamps, braces or other devices. The turnover mechanism is then switched on, the table is inverted and the flask is placed on the table of the stripping mechanism (Fig. 74b). Further, the flask is released from the rollover table, the vibrator is switched on, the mold-receiving table of the stripping mechanism is gently lowered, and the pattern is removed from the half-mold (Fig. 74c). The finished half-mold is then shifted to the roller conveyor and the rollover table is brought to the initial position.

Slip-flask molding. This method is adaptable to the production of molds for casting small pieces in batches. It uses match plates, or double-sided pattern plates (Fig. 75), made of aluminum alloys with the aim of decreasing the mass of plates. The patterns are fixed to the plate on its both sides: a half-pattern 1 is mounted on one side and a half-pattern 3 on the other side of the plate. The gated patterns are also mounted on both sides of the plate.

Slip-flask match-plate molding needs only one molding machine which makes both the drag and the cope. The slip flasks used here are of special construction tapered from top to bottom on all sides, so that they can be easily removed after closing the mold. Before

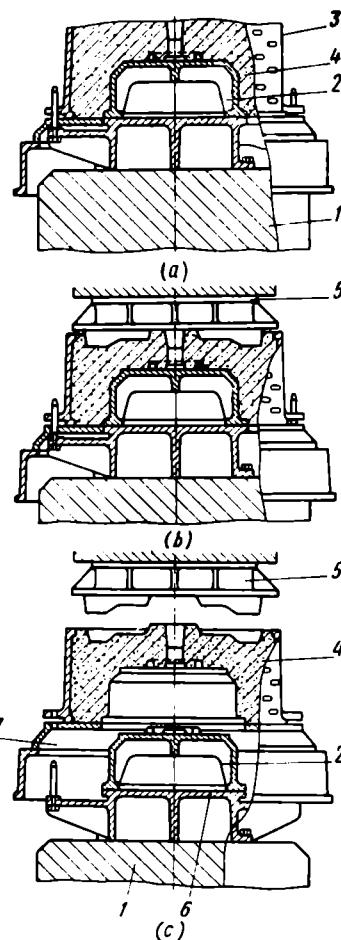


Fig. 73. Stages of manufacture of a mold cope on a jolt pattern-draw molding machine

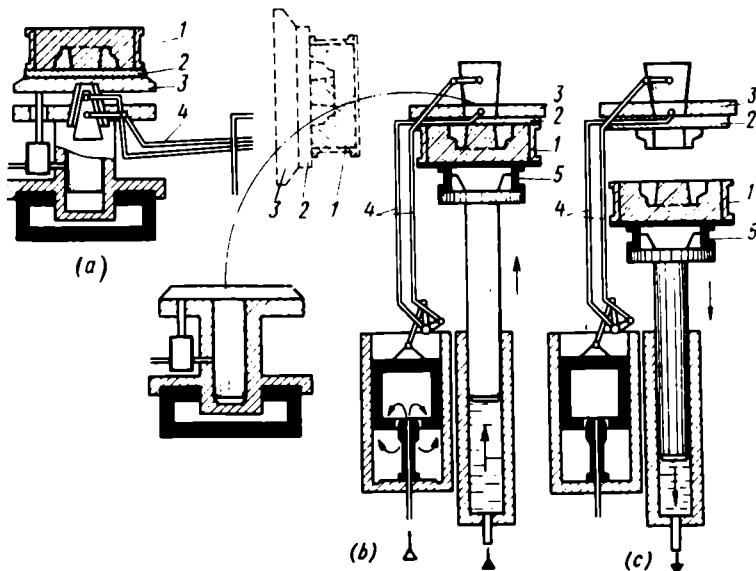


Fig. 74. Stages of manufacture of molds on a jolt rollover-draw machine
 (a) jolting; (b) rolling over the table with a flask; (c) drawing a pattern; 1—flask; 2—pattern plate; 3—rollover table; 4—levers; 5—mold receiving device

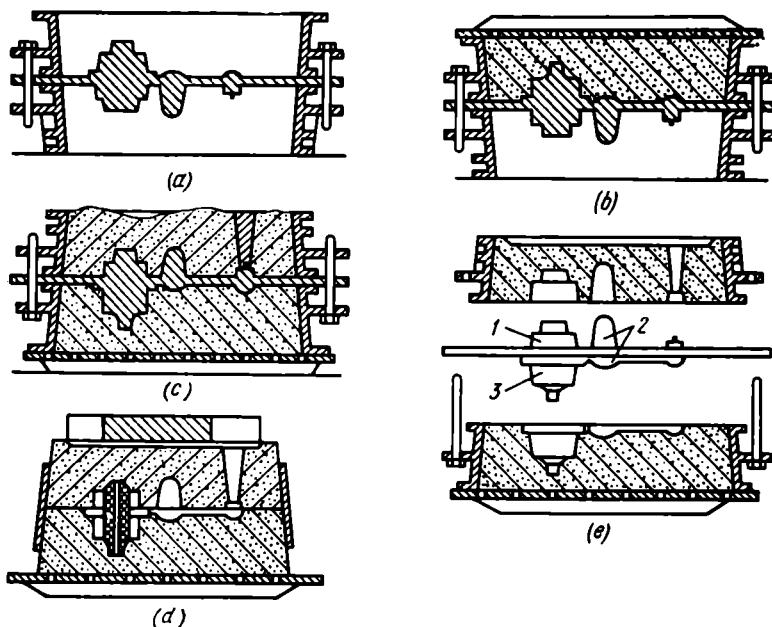


Fig. 75. Stages of slip-flask molding

pouring, wood or metal jackets are placed around the mold to keep it from damage during casting the molten metal. The slip-flask molds produced by this method in the main measure 400×250 mm, 400×300 mm, 450×300 mm, and 450×350 mm, with a height of 150 mm.

The molding procedure begins with the manufacture of the drag. As seen from Fig. 75a, the match plate rests on the inverted flask cope, and the flask drag stands on the match plate. After ramming the drag and placing the plate on the top (Fig. 75b), the assembly is turned over and the cope is rammed (Fig. 75c). This done, the cope is lifted off the match plate, the sprue pin is withdrawn, and the match plate is taken off the drag (Fig. 75e). Next the cores are inserted into the cavity, the cope is placed on top of the drag, and the assembled mold on the plate is conveyed to the pouring station, where a metal jacket is slipped on the mold and a weight is set on the top to keep the cope from lifting (Fig. 75d).

To prevent the cope from shifting relative to the drag and also preclude the escape of metal from the mold over the parting plane, the match plates are provided with locking steps 10 mm in height and with a taper of 45° . The steps also make the cope lighter and facilitate its removal from the match plate.

This method of molding offers important advantages: it cuts off expenses on flasks, for light jackets are much cheaper than accurately sized flasks, and facilitates the shakeout of molds. The method, however, calls for much labor as it includes manual operations in which molders turn over half-molds, lift off and set up in place half-flasks, and so forth. That is why the method finds more and more limited applications.

Automatic flaskless molding. Slip-flask molding has paved the way to the creation of automatic flaskless molding machines of a high productive capacity (over 300-500 molds per hour), which fully exclude manual labor, dispense with costly flasks, secure high-quality castings, and raise the effectiveness of the molding process in the conditions of mass production. Quick-change molding equipment enables the effective use of these machines in batch production too. A machine produces flaskless molds consisting of two half-molds with a horizontally extending parting plane. The machine performs automatically all the molding operations in the sequence analogous to that shown in Fig. 75.

Foundries more often employ automatic lines which make flaskless molds with a vertically extending parting (Fig. 76). The molding sand is rammed here by the method of sand blowing and squeezing. The molds are prepared in molding chambers, using pattern plates 1 and 2. The pattern plate 1 is fastened to the pressure plate of the machine, and the pattern plate 2 to the counterpressure plate. In the initial position, the pattern plates 1 and 2, side walls, plate 7,

and air sand blower head 4 form the molding chamber (position I). Sand 3 is forced from head 4 into the chamber under the action of compressed air (position I). Plunger 5 then compacts the sand, following which the plate 2 moves away and turns aside to give way to

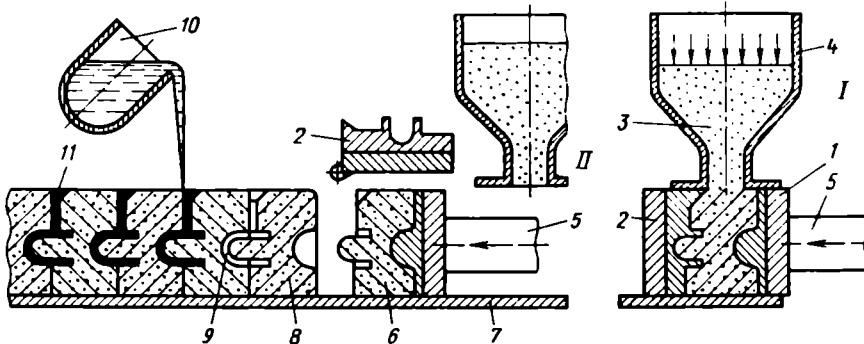


Fig. 76. Scheme of an automatic flaskless molding line

a compacted sand block 6. The plunger 5 now pushes the sand block along the plate 7 until it comes into contact with the preceding sand block (8), thereby forming a cavity 9 (position II). The continuous row of molds so produced are filled with molten metal poured from a ladle 10. The molds are then shifted on to a shakeout grid, where castings 11 are stripped off the sand. After this, the sand is conveyed for reconditioning and reuse, and the castings are delivered to the cleaning and fettling department.

Such automatic lines form molds from high-strength molding sands, of not less than 186 kPa (1.9 kgf cm^{-2}) in the green state. The production capacity of the lines is over 300 molds per hour for casting small shaped pieces from gray, high strength, and malleable iron both with and without cores. The lines are equipped with special mechanisms (automatic coresetters) for inserting cores in the molds.

4.4. ORGANIZATION OF IN-LINE PRODUCTION, INTEGRAL MECHANIZATION AND AUTOMATIZATION IN THE MOLDING SHOP

The productivity of labor and the quality of castings largely depend on the organization of production in the foundry, which either divides or integrates in time and place such processes as molding, pouring, and shakeout.

In piece and small-lot production, foundries commonly operate on the stepwise basis, according to which one production process follows the next.

In the stepwise mode of operation, molding and assembling take place in the first shift, while pouring, shakeout, preparation and cleaning of the molding floor area in the second shift, all the operations being performed on the same floor area.

In the parallel mode of operation, [the foundry performs the production processes simultaneously, during one shift, but on various sites. Conveyors deliver molds for assembling, then for pouring and

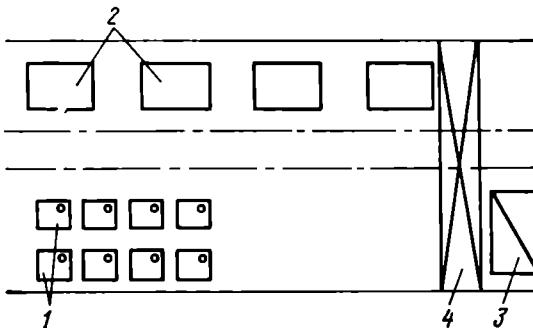


Fig. 77. Scheme showing the disposition of equipment in a foundry operating on stepwise basis

shakeout. The molding machines, assembling and pouring sites, and the working places for molders, pourers, and other workers are located alongside of transporting means. This enables a continuous flow of molds subject to handling, thereby effecting the in-line production of castings.

The parallel mode of work at the foundry is most commonly organized in two shifts. The third shift carries on preventive maintenance, minor repair, and thus prepares the equipment for operation. This mode of operation and the in-line process in particular sharply increase the productivity of labor as against the stepwise mode of work. They are most suitable for mass and large-lot production of castings.

The location of equipment in the molding and assembling departments depends on the mode of work adopted in the foundry.

In the stepwise mode of operation (Fig. 77), half-molds 1 made on machines 2 are assembled in the molding bay at the sites of location of each pair of molding machines. The molds are placed in rows, leaving passageways for pourers and also the central passage along the bay. Crane 4 delivers the poured molds to a shakeout grid 3 and then the same crane transports the empty flasks to molding machines.

In the parallel mode of operation of foundries engaged in mass and large-lot production of castings, every shop or department operates so that the combined effort of all the foundry units results in

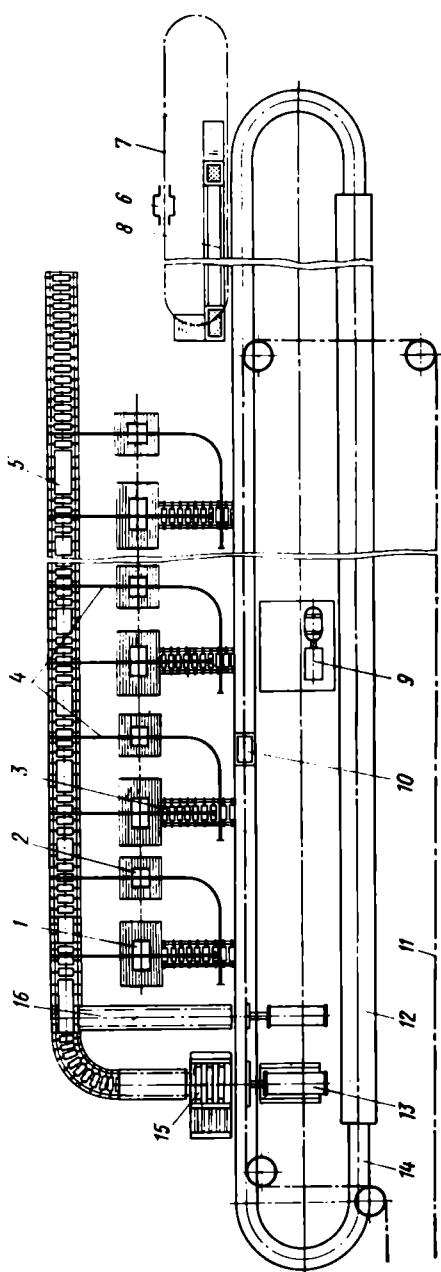


Fig. 78. Molding conveyor system with an endless mold-handling conveyor

a continuous molding process conducted on a conveyor or an automatic molding line.

Figure 78 illustrates a casting conveyor system often employed at foundries engaged in lot production of castings. The conveyor system includes molding machines 1 and 2 which produce drags and cores, respectively, assembled into finished molds on roller conveyors 3. These conveyors transfer the molds to a platform 10 of an endless conveyor 14 which delivers them to the pouring shop. Ladle 6 pours in the molds as it moves on a monorail 7 over a mobile pouring platform 8. The molds filled with molten metal pass through a

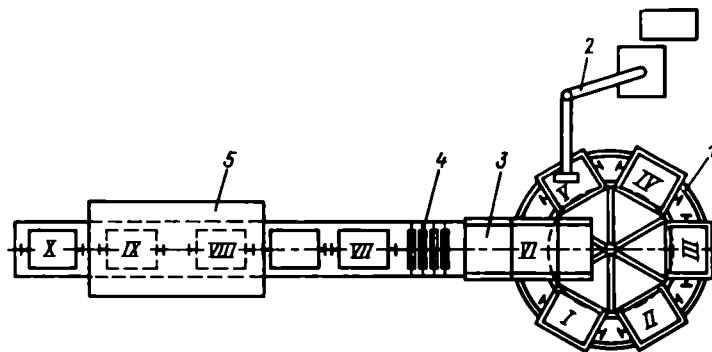


Fig. 79. Mechanized flow line with a sand slinger

cooling installation 12, and then pushers 13 shift them off the conveyor on a shakeout grid 15.

The molding sand shaken out of the flasks passes through the grid and falls on the belt of a conveyor which delivers it to the sand shop for reconditioning. A roller conveyor 5 then transports the empty flasks to molding machines for reuse, and a slat-type conveyor delivers the castings (which slide along from the shakeout grid into the bunker and on to the conveyor belt) to the cleaning shop. Pneumatic lifters moving on a monorail 4 place the flasks on the tables of molding machines. A belt conveyor 16 transfers molding plates taken off the endless conveyor to the roller conveyor 5 which carries them to the molding machines 1 and 2. The endless conveyor has a drive unit with an electric motor 9 which sets the conveyor in motion.

Belt conveyors carry the sand from the sand shop and discharge it into hoppers arranged above the molding machines. Trolley conveyors 11 transport the cores on shelves from the coreroom to the assembly sites.

Mechanized sand-slinging molding line. The line (Fig. 79) consists of an endless conveyor 1, sand slinger 2, tilter 3, roller conveyor 4, and installation 5 for drying molds. The endless conveyor con-

sists of six hydraulically-driven cars moving on the rails and carrying pattern plates and flasks.

In position *I*, a pattern is fixed to the master plate and coated with a parting compound. In position *II*, a flask is set on the plate and filled with facing sand to a certain depth. Positions *I* and *II* are serviced by a cantilever crane. In position *III*, reinforcement hooks are hanged on the flask ribs and the facing sand is compacted.

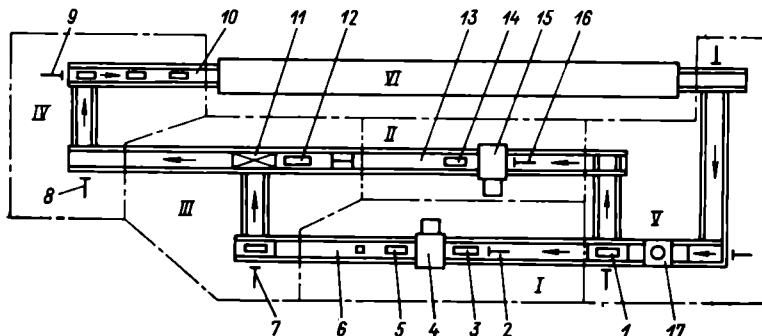


Fig. 80. Automatic molding line

In position *IV*, the flask is filled with backing sand by a sand slinger 2. In position *V*, the top of the half-mold is additionally rammed, the excess sand cut off, the sand pierced through with a vent wire to make vent holes, and the patterns of gates and risers are removed.

In position *VI*, half-molds are turned over to remove the patterns. A half-mold slides off the inclined roller conveyor of the tilter on to the next roller conveyor 4. In position *VII*, half-molds are finished up and washed to make them ready for drying. In positions *VIII* and *IX*, the half-molds are dried in two stages in a drier 5. In position *X*, the half-molds are lifted off the roller conveyor by an overhead crane and transported to the assembly site. The line has a reserve position if the crane is not available. The molds formed on the line are 2 000 to 3 000 mm in length, 1 000 to 2 500 mm in width, and 300 to 900 mm in height. The maximum mass of a half-mold is 2 000 kg. The path of withdrawal of a pattern (the distance from its initial position to the position in which it does not hinder the motion of the mold) is 630 mm (for a flask 900 mm high). The production capacity of the line is four half-molds per hour.

Automatic molding lines successfully operate in the foundries of many machine-building plants. They are noted for high production and reliability in operation. Fig. 80 shows the scheme of one such molding line for the manufacture of molds in flasks measuring 900 × 600 × 150/200 mm.

From the shakeout station, a conveyor delivers flasks to a section I where a release device separates cores from drags. A roller conveyor transports flask cores to a core molding section II, while flask drags go to a drag molding section I.

The roller conveyor carries a flask drag to a tilter 3 which turns over the drag. A pusher 2 then shifts the drag to a single-position squeezer 4 operating from a pneumatic drive and lever booster. The pressure at which the squeezer compacts the half-mold reaches 3.94 MPa (40 kgf cm⁻²). The finished mold drag moves to a tilter 5 which turns it over, and then a roller conveyor 6 carries it to a coresetter.

A pusher 16 transfers a flask core to a squeezer 15, which is similar in design to the drag squeezer 4. From the squeezer, the conveyor delivers the finished mold core to a tilter 14 and then on to a roller conveyor 13, where the pattern imprint in the core is checked for quality.

Molds are assembled automatically in section III. The pusher 7 shifts the drags from the roller conveyor 6 to an automatic assembly machine 11. Since the cores stand on the roller conveyor 13 with the imprints upwards, they first pass through a tilter 12 then go to the assembly machine 11. The closed molds now move on the roller conveyor into section IV. A pusher 8 transfers the molds to the next conveyor, and as they come to a position 10 for weighting and pouring, a pusher 9 shifts the molds onto molding plates mounted on the roller conveyor of cooling section VI. After weighting and pouring the molds, a pneumatically driven mechanism lifts off the weights, and the pusher 9 pushes the poured molds along the roller conveyor of cooling section VI where they cool down under the ventilation hood. The roller conveyor of cooling section VI has two decks. The poured molds move from the pouring section to knockout station V on the upper deck. The molding plates return to the pouring section on the lower deck.

A push-out type machine 17 then knocks out the cooled molds from the two-part flasks. The block of molding sand forced out from the flask together with the casting drops on the shakeout grid which strips the sand from the casting. The output on such a line is at a rate of 180 molds per hour. Four molders service the production line, exclusive of pourers and core-setting workers.

Chapter 5. GATING SYSTEMS

5.1. ELEMENTS OF THE GATING SYSTEM

A most important condition for the production of a sound casting is the right design of the gating system. The main functions of a gating system are to fill steadily the mold and supply metal to the cavity to compensate for shrinkage. The choice of a gating system that would ensure a good quality of castings is the most responsible part of work in elaborating the casting technique.

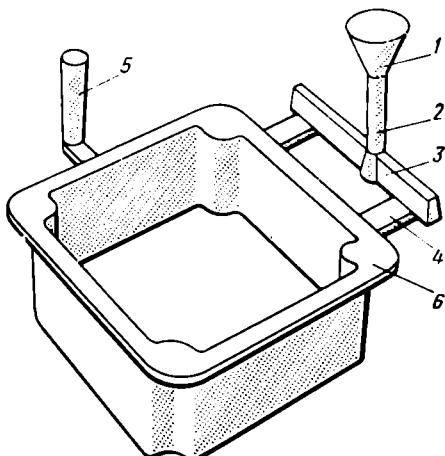


Fig. 81. Iron casting with gating elements

1—pouring cup; 2—sprue; 3—runner; 4—ingate; 5—riser; 6—casting

An ideal gating system must enable the molten metal to fill completely the mold, furnish means for feeding the metal to the casting during its solidification, ensure the desired dimensional accuracy of the casting free of surface defects (sand holes, scabs, slag inclusions, and others), produce directional solidification, and require a minimum of metal for its elements.

Figure 81 shows an iron casting with gating elements. The inlet elements of the gating system are a pouring cup 1, sprue 2, runner 3, and ingates 4. These gating elements must supply the required amount of metal into the mold, regulate the rate of its entry into the cavity, and establish skimming action on dross.

A pouring cup, or a pouring basin (for large castings), is a reservoir at the top of the sprue that receives the stream of molten metal poured from the ladle. Apart from its main function, the cup must retain the slag that gets into it with molten metal. To keep the slag from

flowing down the sprue, it is sometimes useful to close the sprue orifice with a plug (Fig. 82) or tin plates, and thus allow the molten metal to fill up the cup. The plug is then lifted off. The tin plates melt.

During pouring, the cup should be full of molten metal. If the depth of melt in the cup is insufficient, a funnel is likely to form

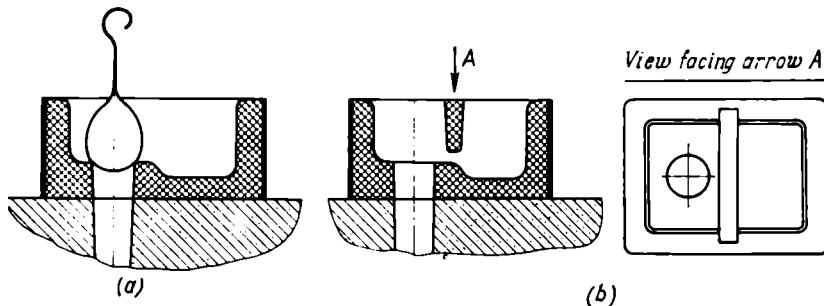


Fig. 82. Pouring cups for running medium-sized castings (a) and large castings (b)

above the sprue orifice, through which the air and slag may get into the sprue and then into the mold cavity (Fig. 83a). When casting small pieces, especially in mass quantities, it is well to retain slag in the cup with strainers (Fig. 83b) prepared from a core sand, chamotte, and refractory fiber materials.

A sprue, or downgate, is a vertical channel that connects the pouring basin with runners and gates. It is made somewhat tapered downward for ease of molding and for the creation of a positive piezometric head in the gating system. The taper of a sprue ranges from 2 to 4°. In molding large castings, the sprue and other channels in the mold are constructed of standardized chamotte tubes.

A runner, or crossgate, is commonly a horizontal channel whose functions are to trap slag and connect the sprue with the gates (ingates), thus allowing the metal to enter the mold cavity.

It is usual to cut runners in the cope and gates in the drag. Runners are commonly made trapezoidal in cross section. While pouring the metal into the mold, it is of prime importance that the melt fills the runner completely to enable a better trapping of slag. To achieve this, the design of the gating system must ensure a certain rela-

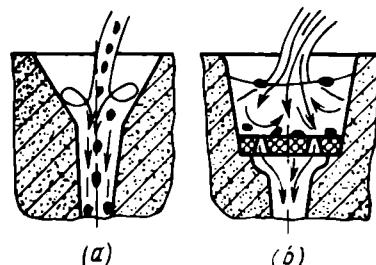


Fig. 83. Scheme of molten metal motion in pouring cups

tion between the cross sections of the sprue, runner, and gate (Fig. 84). If sprue 1 lets pass a larger volume of metal than gate 2, then the metal will fill the runner completely and slag 3 will remain in the runner while floating up to its upper section (Fig. 84a). If the sprue passes less metal than the gate, the runner will be filled only partially and the slag will get access to the casting. So, for the slag to be retained properly, the cross section of the sprue should be larger than

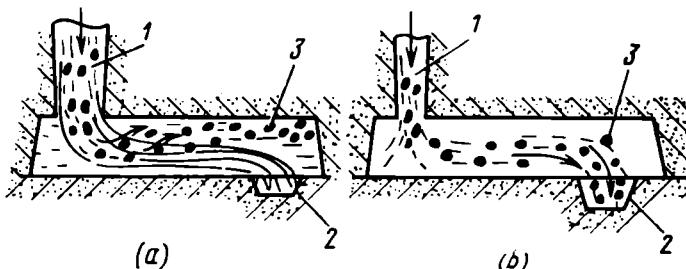


Fig. 84. Scheme of molten metal motion in a filled runner (a) and in a partially filled runner (b)

that of the runner. Also, its cross section should exceed the total cross section of ingates. Such a gating system allows casting under pressure conditions.

Gates (ingates) are channels through which the incoming metal directly enters into the mold cavity.

Gates should have such a shape in cross section that the metal can flow steadily and quietly into the cavity and cool little on the way from the runner to the casting. Besides, the gates should break away readily from the casting after its solidification. Experience has shown that the best shape of gates in cross section is a trapezoid that smoothly passes into a large-area rectangle at the junction with the casting.

If the thickness of the casting body is smaller than the height of the gate at the place where it enters the mold cavity, it is well to shape the gate into a narrow extension (choke) at a distance of 2–2.5 mm from the casting. The gate then would easily break off from the casting at the neck.

Flowoffs are vertical channels that feed the casting and permit the escape of gases from the mold cavity. They also decrease the dynamic pressure of metal on the mold and point to the end of pouring. The mold can have one or several flowoffs depending on its size. The cross section of a flowoff at the base is generally taken to be equal to one-half or one-fourth the cross section of the casting wall. It usually tapers off from top to bottom.

Risers, or feedheads (Fig. 85), are a part of the feeding system. These are reservoirs of molten metal that feed the melt in the casting proper as it solidifies.

They find use in casting pieces from white, alloy, and high-strength iron, and also thick-walled pieces from gray iron. Risers generally feed thick portions of castings. The position of a riser on the

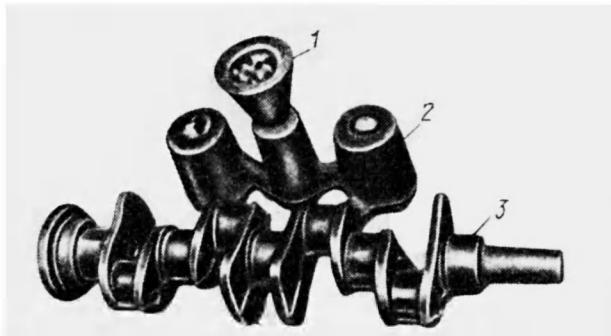


Fig. 85. Nodular-iron crankshaft casting with gates and risers
1—pouring cup; 2—side riser; 3—casting

top of a casting must be such that it can be the last portion to solidify. For this, the riser must be larger in cross section than the member on which it is placed. Large-size risers are economically unjustifiable since they require a rather large amount of excessive metal and greatly add to the cost of the finished casting.

The guiding principles to be observed in risering are as follows:

1. A riser must solidify longer than the portion it feeds.
2. The volume of a riser must be sufficient to compensate for metal shrinkage within the casting.
3. The height of a riser must be such that the shrinkage cavity in the riser will lie above the neck (a portion that connects the riser with the casting). The neck should be as short as possible and also solidify longer than the casting. If the casting has several thickened portions separated by thin walls, a riser must be placed on top of each thick member.

Since risers find most extensive uses in the manufacture of castings from steel and nonferrous alloys, the design and calculation features of these feeding elements will be considered in more detail in pertinent Sections.

5.2. GATING METHODS AND TYPES OF GATING SYSTEMS

In choosing the method of gating and the design of a gating system, it is necessary to keep in mind that the molten metal must steadily flow into the mold, without swirling or impinging on the projecting parts of the mold and cores, at a rate that ensures a preset rise of metal in the mold. Also, the pouring method must permit gradual escape of the air and gases from the mold and enable directional solidification of the casting, taking into account its shape and the properties of the alloy cast.

In gating of gray iron castings, it is common to supply the metal to a narrow portion of the casting in order to level off the rate of cooling in its individual portions. As it passes through a narrow portion of the casting, the metal heats up the mold at the inlet section and goes on moving now cooled to a certain extent into a massive part of the casting. The thin portion in the heated part of the mold and the massive part filled with a somewhat cooled metal solidify at the same rate, which makes for a higher quality of the casting, decreases internal stresses and warpage.

However, in running of castings with massive members, along with the method of supplying metal to a casting through its narrow portion, in use is the gating method by which the gate delivers the metal to a massive part, into the base of the riser, in order that the metal in the riser may long stay in the liquid state and thus feed the casting.

The melt that fills the mold should not flood core seats or impede the escape of gases from the core and mold. The pouring rate (rise of metal in the mold per second) must be sufficient for the gases being evolved and the air found in the mold cavity to leave freely the mold. On the other hand, a slow pouring may lead to a decrease in the fluidity of metal, to poor filling of the mold, and, in large molds with a developed metal surface, to excessive heating of mold walls due to thermal radiation of the melt, to the appearance of scabs, and slag spots on the surface of the casting.

The types of running used with each of the chief gating methods are bottom gating, mold-joint gating, top gating, step gating, and composite gating. Each of the gating methods has its own advantages and disadvantages. The choice of a gating method depends on the shape of the casting, the purpose it must serve, and the metal employed.

Mold-joint gating (Fig. 86). The systems of this type of gating are the simplest and find wide use for running various castings in molds having a depth of the cavity from the parting line to its lowermost point up to 200 mm (the allowable height from which the incoming metal falls on the bottom of the mold without causing perceptible damage to the walls). When using such gating systems, one

should take account of the mass of melt and its pressure on the mold walls, which depends on the sprue height.

Bottom gating (Fig. 87). The bottom gating systems allow the quiet flow of metal into the mold. In casting a gear, for example,

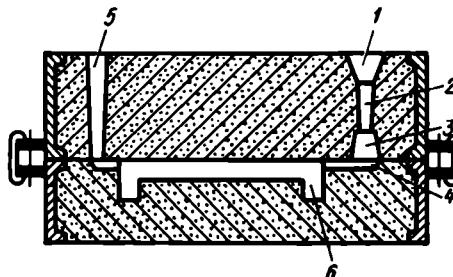


Fig. 86. Mold-joint gating system

1—pouring cup; 2—sprue; 3—runner; 4—gate; 5—riser; 6—casting

the metal enters the casting through the gate that runs to the bottom of the hub, but not to the teeth. Bottom gating is applicable for running both small and large castings. In the mass production of small

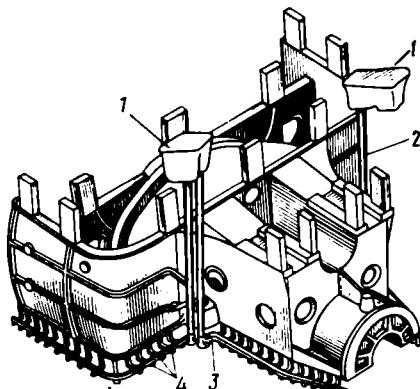


Fig. 87. Bottom gating system for an iron casing casting

1—pouring cup; 2—sprue; 3—runner;
4—ingates

castings, however, molding machines are rarely used to prepare molds for bottom pouring since the gating system here calls for the production of special cores.

Top gating. The gating systems of this type are employed to run both medium-size and large castings such as flywheels, gears, and cylinders. In the shower-type top gating system (Fig. 88), the metal runs into the mold from the top through a shower gate that consists of several small-diameter pencil gates cut in the pouring cup or in a special core. The shower gate has the disadvantage of producing a splashing effect: as the stream of metal falls on the mold bottom or

on the surface of the melt, it splashes and thus forms on the mold walls beads (buttons) of solidified metal that does not weld up with the basic metal of the casting. A combination of the bottom gate and the shower gate used in practice does away with this drawback.

An important feature in favor of the shower-type gating system is that the metal uniformly fills the mold without overheating its individual portions. This results in a sound casting free of porosities and shrinkage cavities.

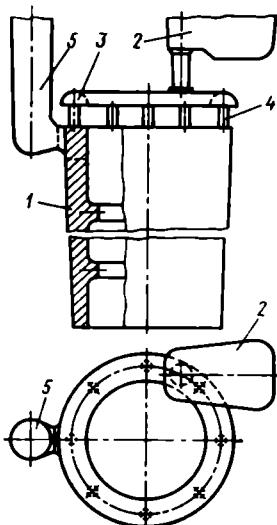


Fig. 88. Top gating system with a shower gate for an iron cylinder casting

1—casting; 2—pouring cup; 3—runner; 4—pencil gate; 5—side riser (flowoff)

pouring. The metal then runs through branched vertical runners 5 into gates 6. Because the runners 5 have a larger cross section than the choke 4, the melt first goes into the lower part 7 of the casting and then into its upper part through the next gates. Such a system excludes overheating and erosion of the mold at the inlet to the cavity and enables the production of high-quality castings.

Stack gating (Fig. 91). This system of gating is employed in stack molding of small castings and also in casting of small pieces on automatic flaskless molding lines producing molds with a vertical parting joint (see Fig. 76). The ingates for every row of castings differ in cross section: the higher the position of a gate, the larger its cross-sectional area, with the result that the pouring time for every casting becomes the same.

The gating method and the design of a gating system and its elements depend not only on the shape and size of the casting, but also

Composite gating. The gating systems of this variety serve for running intricately shaped, high, thin-walled castings. The system shown in Fig. 89 is a combination of the bottom gate and the shower gate. The mold is first poured through the bottom gate and then through the shower gate. This pouring method prevents mold erosion and metal splashing. As the metal fills the mold, its level in the sprues gradually rises, and, starting at a certain moment, the upper gates begin to feed the casting.

Step gating (Fig. 90). Step-gate systems are used for running large and heavy castings. The step-gate construction shown in the figure enables subsequent feed of the casting through the gates from the bottom upwards. The molten metal flows from a basin 1 down a sprue 2 and into a runner 3 through a choke 4 whose cross section determines the rate of

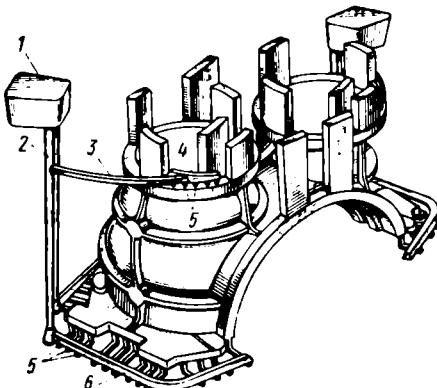


Fig. 89. Composite gating system for a casting

1—pouring cup; 2—sprue; 3—running channel; 4—upper runner; 5—ingates; 6—lower runner

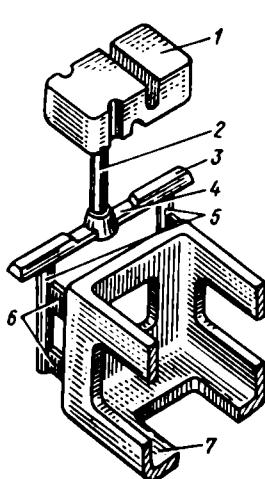


Fig. 90. Step gating system

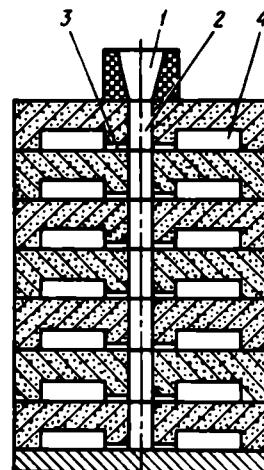


Fig. 91. Stack gating system

1—pouring cup; 2—sprue; 3—gates;
4—casting

on the properties of the alloy cast. The features of gating systems used for the running of castings from malleable iron, steel, and non-ferrous alloys are considered in appropriate Sections.

5.3. CALCULATION OF GATES FOR GRAY IRON CASTINGS

In devising a technique for the production of an iron casting, the technologist-founder must choose a gating method and determine the size of gating elements. The latter factor is of great importance be-

cause the gating system has a direct influence on the quality of the casting and also on the cost of the finished product, since the mass of gates and risers may be excessively large depending on the mass of the piece being cast.

The casting yield is the ratio between the mass of sound castings and the mass of metal spent on the castings proper, gates, risers, rejects, and scraps (splashings, spillages, residues in the ladle). This ratio is always less than unity and on the average is equal to 0.85-0.95 for massive castings of simple shape, such as plates and iron molds; 0.75-0.85 for steel castings of simple shape; 0.65-0.75 for heavy iron machinery parts; 0.55-0.65 for heavy steel machinery parts; 0.45-0.55 for small iron pieces; and 0.35-0.45 for small steel pieces.

The casting yield is an important factor indicative of the technological level. It is clearly desirable to spend as little metal on gates and risers as possible and thus increase the casting yield.

The proper design of a gating system is of great technical and economic significance since the right dimensioning of gating elements permits cutting down the amount of metal required for gates and risers and decreasing casting rejects.

The task involved in determining the right dimensions of gates is difficult to handle in each concrete case because of the complex processes occurring during the pouring period. In practice, technologists resort to approximate methods of calculation which rely on the following assumptions: the melt is regarded as an ideal liquid of constant viscosity; the cooling of the melt and heating of the mold during pouring are neglected; the metal motion is considered as being a steady motion of heavy liquid in blind and open channels of the mold.

Calculation of a gating system by a hydraulic method. First, we find the total cross-sectional area of gates and then the dimensions of other gating elements, namely, of the sprue and the runner.

The total cross section of gates is calculated by the formula

$$F_g = \frac{G}{\rho t v} = \frac{G}{\rho t \mu \sqrt{2g H_s}} \quad (9)$$

where G is the mass of the casting, g , ρ is the density of melt (for molten iron, $\rho = 7 \text{ g cm}^{-3}$), t is the pouring time, s, v is the pouring speed, cm s^{-1} , μ is the coefficient allowing for friction; g is the gravitational acceleration, cm s^{-2} , H_s is the rated static head, cm.

The unknown quantities in formula (9) are H_s , μ , and t . The rated static head depends on the size of the casting and is determined from the relation

$$H_s = \frac{2HC - P^2}{2C} = H - \frac{P^2}{2C} \quad (10)$$

where H is the height of the sprue from its top to the point of metal entry into the mold cavity, cm, C is the height of the casting, cm,

and P is the height of the casting from its top to the point of metal entry into the cavity.

In bottom gating (Fig. 92a), $P = C$, $H_s = H - C/2$. In top gating (Fig. 92b), $H_s = H$. For gating at the mold parting (Fig. 92c), taking $P = C/2$,

$$H_s = H - \frac{C}{8}$$

The pouring time for intricately shaped thin-walled castings (with walls of 1.5 to 2.5 mm in thickness and up to 450 kg in mass) is

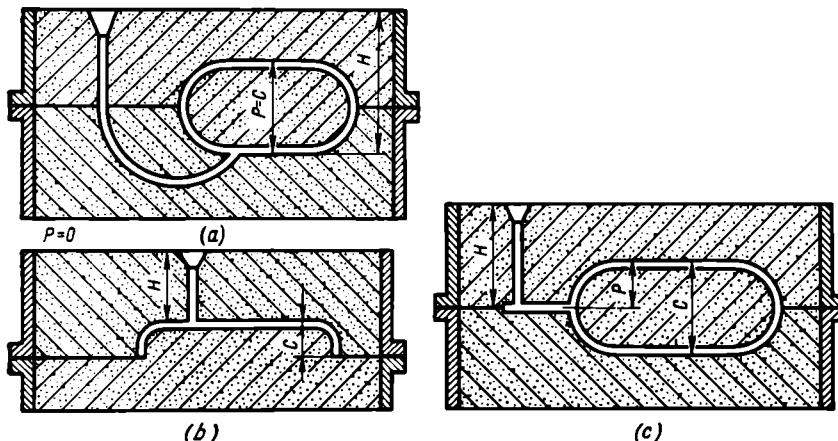


Fig. 92. Calculating metal head in pouring a mold

found from the formula

$$t = s \sqrt{G}$$

where G is the mass of the casting with gates and risers, kg, and s is a coefficient used to account for wall thicknesses. With wall thicknesses of 2.5 to 3.5 mm, 3.5 to 8.0 mm, and 8 to 15 mm, the coefficient s is respectively equal to 1.68, 1.85, and 2.2.

For medium-sized and large castings up to 1 000 kg in mass,

$$t = s \sqrt[3]{G\delta}$$

where δ is the thickness of a casting, mm:

δ , mm	To 10	20	40	To 80 and over
s	1.0	1.35	1.5	1.7

It is much more difficult to determine the friction coefficient which characterizes the total hydraulic resistance the mold offers to the moving metal. It depends on friction coefficients μ_1 and μ_2 for the gat-

ing system and the mold respectively:

$$\mu = \mu_1 \mu_2$$

According to research data, the value of μ for iron castings varies from 0.75 to 0.85; in other words, the loss in the gating system due to friction in channels, turnings, narrowings, and also due to swirling and other influences is equal to approximately 20%. The coefficient μ_2 for the mold primarily depends on the casting shape, the amount of gases evolved, gas permeability, moisture content, swirling, and impacts of metal on protruding parts of the mold. The coefficient μ is impossible to calculate. Practice is the only source that helps establish its values for use in calculations. Thus, for thin-walled iron pieces (with walls up to 10 mm thick) cast in molds of high hydraulic resistance, μ is equal to 0.34.

Substituting the values of μ , t , and ρ into formula (9), we obtain

$$F_g = \frac{G}{0.34s \sqrt{G} 0.31 \sqrt{H_s}}$$

Denoting $\frac{1}{0.34 \times 0.31}$ by x , the formula takes the form

$$F_g = \frac{x \sqrt{G}}{\sqrt{H_s}} \quad (11)$$

For castings with wall thicknesses of 2.5 to 3.5 mm, 3.5 to 8.0 mm, and 8 to 15 mm, the values of x are respectively equal to 5.8, 4.9, and 4.3.

It is evident from the formula that as the wall thickness of a casting diminishes, with its mass remaining invariable, the total cross-sectional area of the gates grows, and vice versa.

Knowing F_g , we are now able to determine the cross section of the runner, F_r , and that of the sprue, F_s , for the following castings:

thin walled: $F_g/F_r/F_s = 1/1.06/1.11$

small and medium-sized: $F_g/F_r/F_s = 1/1.1/1.15$

medium-sized and large: $F_g/F_r/F_s = 1/1.5/2$

large: $F_g/F_r/F_s = 1/1.2/1.4$

Calculation of a gating system with the aid of the Sobolev nomogram.

Generalizing a large amount of practical data on the design and calculation of gating systems, the engineer K.A. Sobolev has worked out a nomogram which simplifies the calculation of a gating system. This nomogram (Fig. 93) is suitable for the calculation of the cross-sectional areas of gates for medium-sized machinery castings. Using the diagram, we can determine the total cross section of gates, F_g , depending on the mass of the casting, G , its wall thickness δ , and rated static head H_s .

Assume that we must calculate the gate for a 900-kg iron casting whose wall thickness is predominantly equal to 15 mm. The rated height of the sprue is 60 cm. The mold for the casting offers moder-

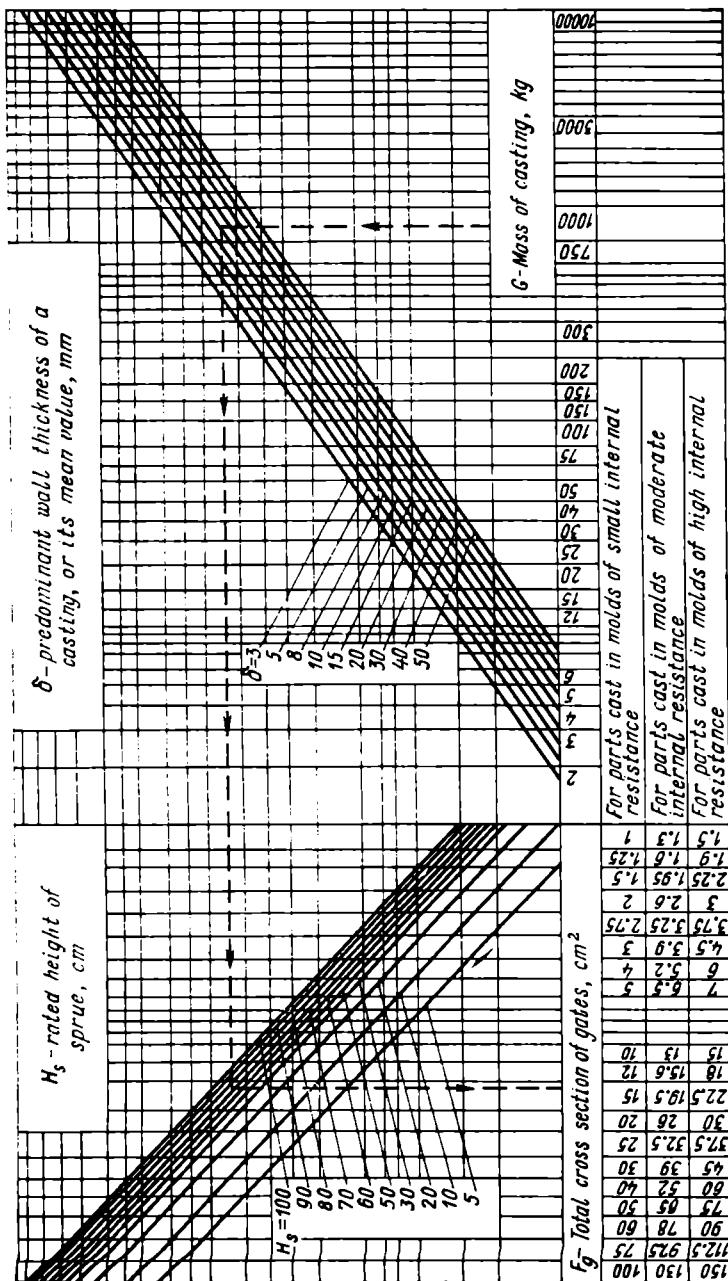


Fig. 93. Soholev nomogram for calculating the cross sections of gates

ate hydraulic resistance to the metal flow. In the right part of the nomogram, we find a point corresponding to 900 kg, and then erect a perpendicular from this point until it intersects the inclined line representative of a wall thickness of 15 mm. From the point of intersection, we now draw a line parallel to the X-axis until it cuts the

inclined line for the 60-cm rated head. Next we drop a perpendicular from the point of intersection to the X-axis. The resultant point of intersection gives us the total cross-sectional area of gates, F_s , for the given casting, which is equal to 19.5 cm². The nomogram is applicable for determining the total cross section of gates for green-sand molds. In pouring molds in the dry condition, it is necessary to introduce a correction factor, equal to 0.8-0.85.

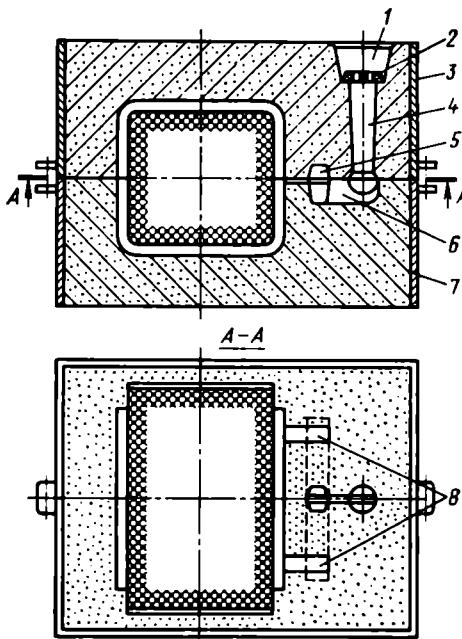


Fig. 94. Mold with a choke-type gating system
1—cup; 2—strainer; 3—cope; 4—sprue; 5—runner; 6—choke; 7—drag; 8—ingates

Design and calculation of choke-type gating systems. The gating systems whose elements, from the sprue to the gates, show a gradual decrease in cross section, may sometimes cause defects such as slag pits and sand holes, which form through erosion of the mold by the metal flowing out from the gates at a high speed.

The gating systems with chokes (Fig. 94) provide for the regulation of the speed of metal flow into the mold cavity and better trapping of slag. Chokes are narrow, slit-type channels disposed between the sprue and gates. The choke controls the mass rate of metal flow through the gating system, and the gate determines the linear speed of melt entering the mold cavity. The linear speed of metal flow should be as small as possible, but sufficient for the metal to fill completely the runner cross section. The cross section of the runner should be such as to keep the speed of metal that flows through it below the critical value at which the metal entraps the slag.

As molten metal flows through a choke, the turbulent intermixing in the stream decreases and, since the speed of the metal stream slows

down, the slag floats up as it leaves the choke. An increase in the cross section of a gate decreases the speed of metal entry into the mold cavity and thus diminishes the number of sand holes in castings.

The gating systems with chokes are calculated by the method of professor B. V. Rabinovich. Consider the sequence of stages involved in the calculation of the dimensions of gating elements.

1. Knowing the position of the casting during pouring, we have to determine the point of metal entry into the mold cavity, make up the scheme of the gating system, and find the rated static head from formula (10).

2. From the diagram of Fig. 95, we define the mass rate of pouring, G_p , knowing the mass of the casting with gates and risers and having chosen the pouring rate (fast, moderate, slow). Slow running is advisable for thick-walled gray iron castings, for castings with massive vertical walls, and for castings with large cores and small core prints. Fast running is expedient for intricately shaped thin-walled castings, for castings gated at the bottom, and also for castings with developed horizontal surface. In other cases, it is preferable to run castings at a moderate speed.

3. Knowing the mass rate of pouring and the rated head, we determine the choke number from the diagram of Fig. 96. Next, using Table 22, we find the dimensions of the choke according to its number and design.

4. From the mass rate of pouring, it is now necessary to estimate the cross-sectional area and other dimensions of the runner, and also the total area of gates. For this, on the Y-axis of the nomogram shown in Fig. 97, we find the rate of metal flow through the runner branch being calculated (if the runner branches from the sprue on two sides, we have to take the half-rate of metal flow through the selected choke). From the point of flow rate, we draw a horizontal line until it cuts curve I. Next, from the point of intersection, we drop a perpendicular through the X-axis and further until it cuts curve II. From this second point of intersection we draw a horizontal line to the left up to the Y-axis. The ordinates here are the dimensions of the runner base, P (mm), the other dimensions of the runner being given in the graph ($h = P$, $h = 0.75P$). The cross-sectional area of the runner, F (cm^2), is plotted on the X-axis.

Similarly, using the diagram of Fig. 97, we determine the total cross section of gates. For this, we find on the Y-axis the rate of metal flow through a runner branch and draw a horizontal line up to its intersection with curves 1, or 2 or 3, depending on the design of junction of the gate with the runner and the casting. From the point so found, we drop a perpendicular on to the axis of abscissas, which are the cross-sectional areas of gates. The number of gates to be cut and their positioning depend on the design of the casting.

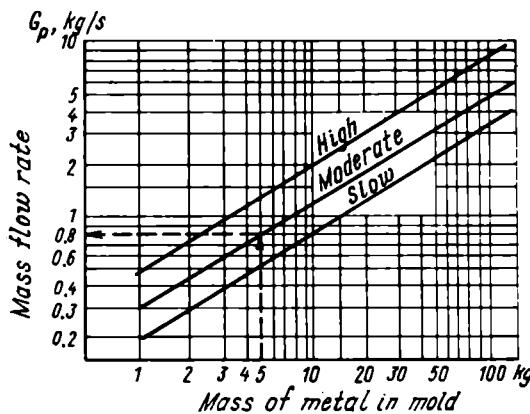


Fig. 95. Determining the mass rate of metal flow into a mold

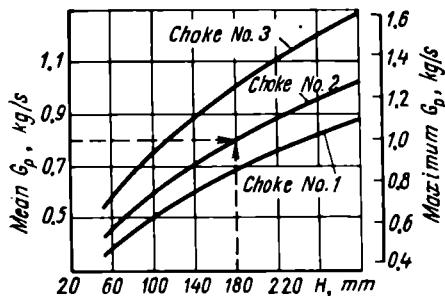


Fig. 96. Diagram for determining the choke number

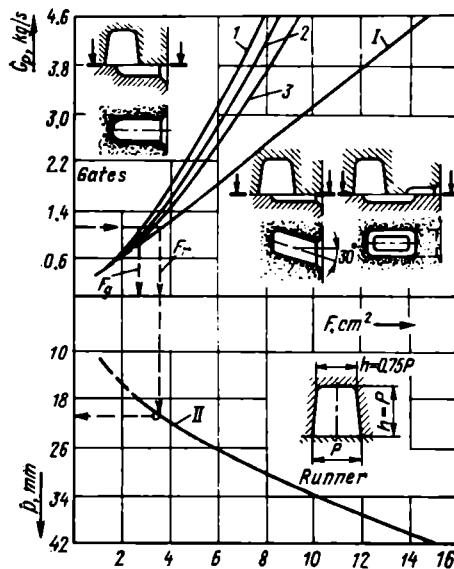
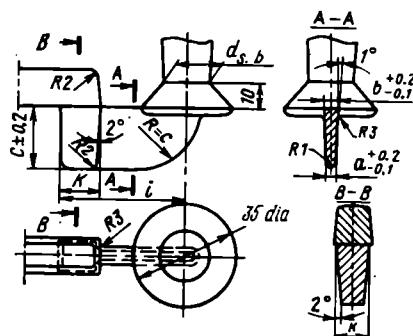


Fig. 97. Nomogram for determining the cross section of runners and gates from the known flow rate

Table 22

The Dimensions of Single-Pass, Single-Way Chokes, mm



Choke number	Total cross section, $\sum F_{ch}$, cm ²	$a^{+0.2}_{-0.1}$	$b^{+0.2}_{-0.1}$	$c \pm 0.2$	i	K
1	1.0	3.6	4.5	24.6	45	15
2	1.5	4.5	5.5	30.0	45	15
3	2.0	6.0	7.0	30.8	48	18

Note. The diameter of the sprue at the bottom, $d_{s.b} = 18$ mm.

5. Knowing the flow rate, we find the diameter D of the cup and its height h from Table 23.

Table 23

Size of Pouring Cups

Cup number	G_p , kg/s	$D = h$, mm
1	To 1.5	50
2	1.5-2.5	60
3	2.5-3.5	75
4	3.5-5.0	90

Calculation of a gating system by the specific speed of pouring. This method is suitable for dimensioning the gates for large iron castings. The total cross-sectional area of gates is calculated with the

formula

$$F_g = \frac{G}{t K_s} \quad (12)$$

where K_s is the specific speed of pouring, $\text{kg}/(\text{cm}^2 \text{ s})$.

The unknown variables in formula (12) are t and K_s . The time of pouring is found from the formula

$$t = s \sqrt{2pG}$$

where p is a constant equal to 0.62 (the criterion for its calculation is the assumption that 1 ton of iron is poured for 35 s).

The specific speed of pouring, K_s , is taken from the diagram of Fig. 98. First, we determine the volume ratio:

$$K_V = \frac{G}{V}$$

where G is the mass of liquid metal filling the mold cavity, gates and risers, and V is the casting volume measured within the extreme points on the drawing, dm^3 . Knowing K_V , we can find K_s from the graph and then determine F_g by substituting into formula (12) the known values of t and K_s .

The cross-sectional area of gating elements may be estimated from the relation

$$F_g/F_r/F_s = 1/1.2/1.4$$

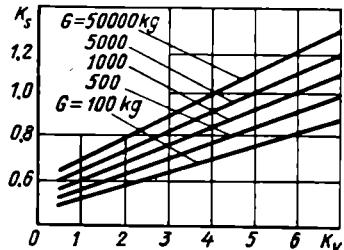


Fig. 98. Calculating the specific speed of pouring

Chapter 6. COREMAKING

6.1. GENERAL

Cores are sand bars designed to form holes and cavities in castings and also to shape outer surfaces of cast pieces. Metal usually envelops a core on all its sides as it fills the mold cavity. That is why cores must feature high gas permeability and strength, and good deformability and collapsibility. The right choice of core sand and the proper design of cores ensure the above properties.

Cores are divided into five classes (see Part I, Sec. 3.6) according to their shape and the conditions in which they have to operate.

Cores are made in core boxes or with the aid of templates both manually and mechanically by resorting to the same methods as are adaptable to the production of molds.

6.2. CORE DESIGN

To mold a casting with holes and cavities of the desired dimensions, as specified in the casting drawing, it is necessary to properly locate the core in the mold, apart from making it to accurate geometrical size.

For this the core must have a sufficient number of core extensions of certain length.

Core extensions (or *core prints*) secure a steady position and accurate location of the core in the mold and permit the escape of gases evolved from the core during pouring. The core extensions must be so dimensioned as to withstand the load resulting from the mass of the core proper and the pressure of metal on the cope and core. Also, they must have such a shape as to exclude any shifting of the core. The criterion for dimensioning core extensions is the least core bearing surface which enables the pressure acting on the mold portion at the junction with the core extension not to exceed 50 to 75% of the sand compression strength σ_c . The surface area of a drag print (Fig. 99) depends on the core mass Q . It is found from the formula

$$S = \frac{Q}{\sigma_c}$$

After pouring the metal into the mold, the core may be regarded as a body submerged into a liquid. Then the upward force of the core that acts on the cope is

$$P = V\rho - Q$$

where V is the volume of the core without prints, ρ is the metal density, and Q is the mass of the core with prints.

The surface area of every core print (Fig. 99a) is found by the formula

$$S = \frac{0.5P}{\sigma_c}$$

The buoyant force of the core for the case considered in Fig. 99b is

$$P = \frac{\pi}{4} (D_1^2 - D_2^2) H \rho - Q$$

Knowing the number of cope prints and the compression stress σ_c permissible for the cope, we can calculate the minimum bearing

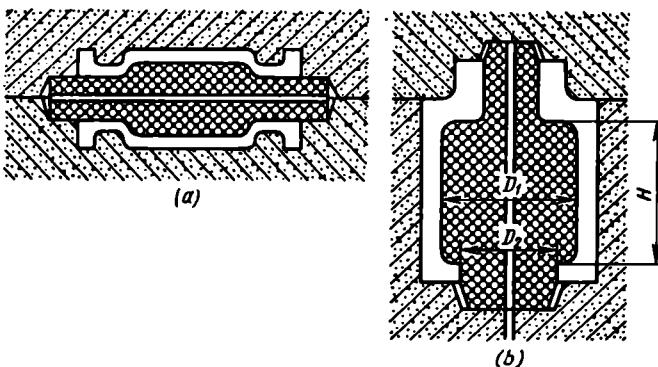


Fig. 99. Relating to the calculation of core print dimensions for a horizontal core (a) and vertical core (b)

surface for cope prints. If the calculations show that the number of prints and their surface area are insufficient and it is impossible to extend the prints, the use of metal chaplets installed in the mold to support the core in the desired position can remedy the situation.

Locking means (flats or registers) provided on core extensions (see Fig. 134) secure the steady position of cores in the mold. For horizontally positioned cores with two extensions, the flats are provided only on one of the extensions.

Core frames. These are the reinforcement means molded into cores to increase strength. The frames are made from wire or shaped cast iron plates. The core reinforcement must fulfill the following requirements: give sufficient strength and rigidity to the core, not spring or come off the core sand (soft, annealed wire will do for the purpose), deform readily to allow for contraction of the casting, not stand in the way of vent holes being made, and permit easy shakeout of the core from the casting.

Thin cores are reinforced with 1 or 12-mm wire inserted into the core boxes during core molding.

Small and moderately sized cores are made with 6 to 10-mm wire frames whose separate parts are fastened with a thinner wire. The reinforcement means for large sand-clay cores are iron and steel cast frames with 6 to 10-mm cast-in wire inserts.

The framework for medium-sized and large cores includes lifting arrangements by which the cores are suspended on the crane for delivering them to the assembly site. Fig. 100 shows wire and cast frames made in various shapes. Wire frames are laid along the length of the core. They should terminate at least 2 or 3 mm short of the core ends. The frame should pass into the prints to add to the core strength. If the core has two prints located opposite each other, the frame should extend into both.

The wire that makes up the frame proper is the *basic* wire, and that which runs around the frame periphery and strengthens individual parts of the core is the *binding* wire. It is impermissible to place the frame wire too close to or directly on the surface of the core, otherwise the frame may weld to the casting and cause the formation of blowholes and hot tears. The distance from the wire frame to the core surface must be 5 to 10 mm. For cast frames, this distance in cores measuring 500×500 mm, $(500-1\ 000) \times (500-1\ 000)$ mm, and over $1\ 000 \times 1\ 000$ mm ranges from 20 to 30 mm, 25 to 30 mm, and from 30 to 35 mm respectively.

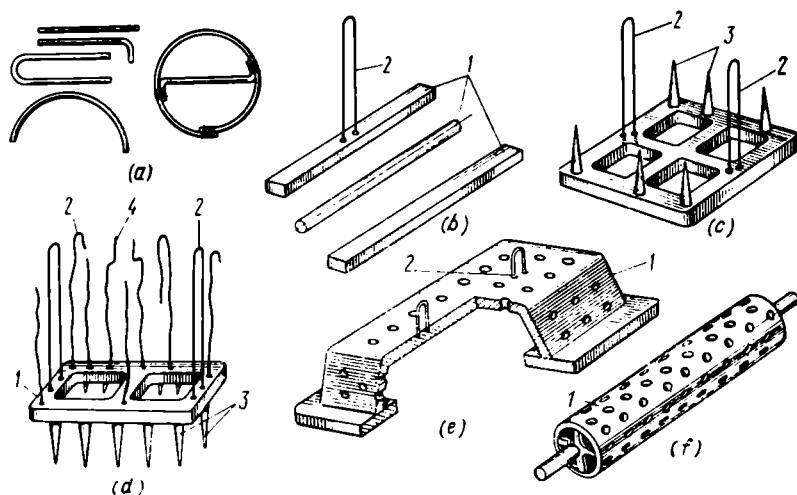


Fig. 100. Core grids (frames)

(a) for small cores; (b) for small cylindrical cores; (c) through (e) for prismatic cores; (f) for large cylindrical cores; 1—base; 2—lifting arrangement; 3—cast-in pins; 4—wire elements

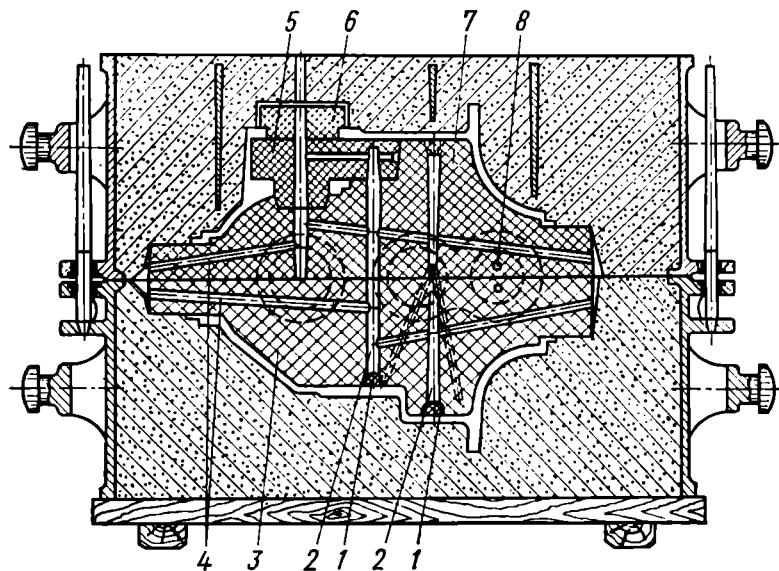


Fig. 101. Layout of the vents in cores and in the mold for an iron casting
 1—core plugs; 2—vertical vents; 3, 5, 6, 7—cores; 4, 8—inclined and horizontal vents

If a core should have only one frame, this is placed in the center of its cross section. Several frames should be positioned uniformly over the core cross section. If a core has a curved axis, it is better to set up a few thin frames instead of a single thick frame in order to facilitate the core shakeout from the casting.

It is undesirable to use core reinforcement in the mass production of castings since this complicates the coremaking process and the core shakeout procedure. The required strength of cores is often possible to achieve by using high-strength core sands.

Core venting (Fig. 101). While pouring the mold with molten metal, mold walls and cores heat up rapidly and give off a large volume of gases. Since the molten metal has a particularly strong effect on cores, these must have vent holes. The venting consists in making holes with a vent wire, with steel rods or pipes molded into the cores and subsequently removed after core molding, by inserting wicks (which form holes after wax melting and cord removal), capron mesh tubes, straw braids (in casting pipes and cylinders), and by packing up coke ash inside large cores during core molding.

In two-part cores, vent holes are cut along the parting surface in one or two core halves. The vent holes made with pins passed through the orifices in core boxes produce the best effect. After ramming

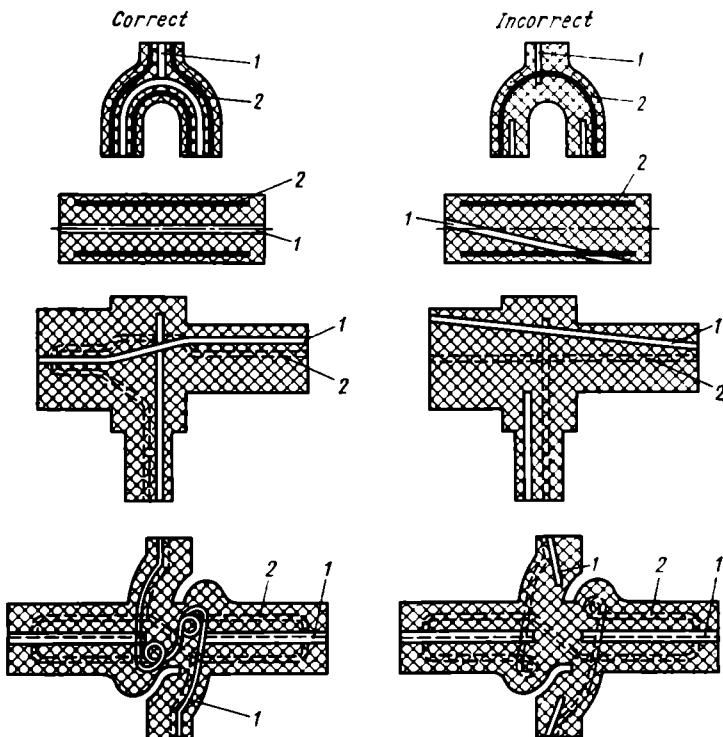


Fig. 102. Variants of laying out vents 1 and grids 2 in cores

the core sand in the box and removing the pins, vent holes result. The correct and incorrect methods of core venting are illustrated in Fig. 102.

6.3. HAND COREMAKING

In the piece and small-lot production of castings, it is common practice to make cores manually in core boxes and with the aid of templates.

The production of cores in core boxes is the most widespread method, which is rather simple and effective.

Making a core in an unsplit knockout-type core box. After blowing out the box (Fig. 103) with an air jet and cleaning, the coremaker sprays a parting mixture over its surface. Then he fills the box with sand (Fig. 103a) either directly from the hopper or by using a small scoop or shovel, depending on the size of the core.

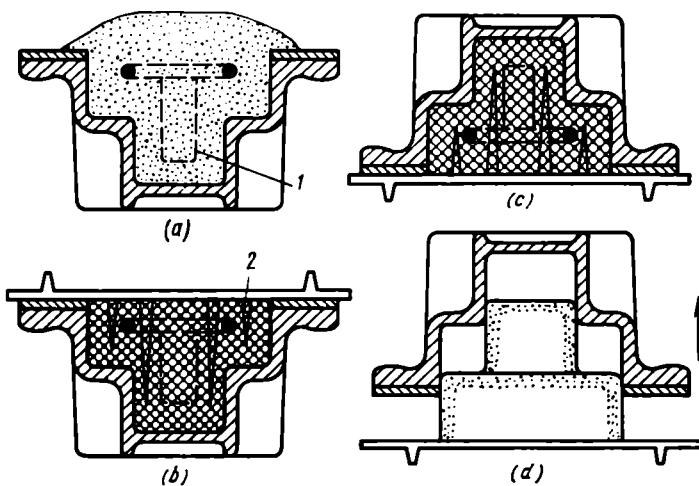


Fig. 103. Making a core in an unsplit knockout-type core box

He now inserts into the box a wire frame 1 to give more strength to the core and rams the sand with a hand or pneumatic rammer fitted out with tips made of rubber or soft nonferrous alloy. After ramming, he makes vent holes 2 (Fig. 103b), then turns over the box (Fig. 103c) and strips it from the core (Fig. 103d). The finished core is then conveyed to a drier.

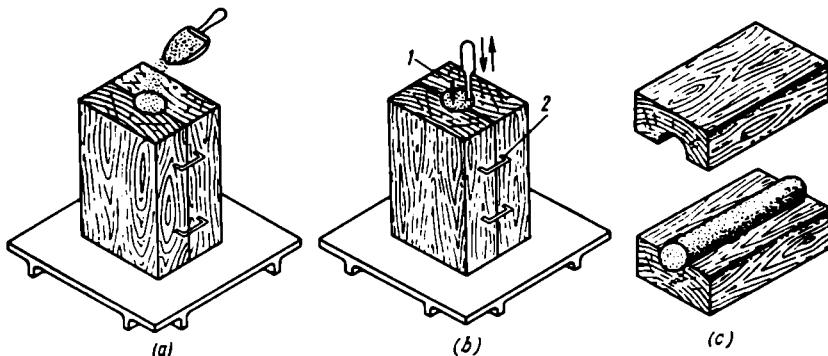


Fig. 104. Making a core in a split wooden core box

Making a core in a split core box. Fig. 104 gives an example of making a core from lowered-strength sand in a split wooden core box. First the coremaker fastens together the box halves with clamps and

places the box vertically on the bench. He then gradually rams the sand, layer after layer, into the box (Fig. 104a, b), trims it off level along the top face, inserts a reinforcement wire 1, vents the core, and then gently knocks on the box with a mallet to facilitate the core removal. It should be remembered that too sharp and hard blows can deform the core.

Next the coremaker loosens clamps 2, lifts off one box half (Fig. 104c), withdraws the core from the box, and places it on a drying

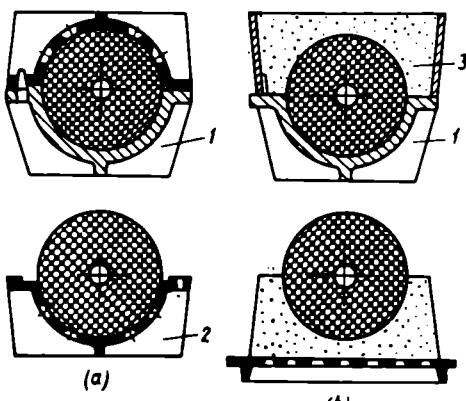


Fig. 105. Laying a core on a shaped drying plate (a) and in a sand bed (b)

1 — core box half; 2 — shaped plate; 3 — sand bed

board or plate for transportation to an oven. If a shaped drying plate is not available for a core of complex configuration, a sand bed can do well, which is made in the following manner. After taking off the upper half of the box, the coremaker places a metal or wooden frame on top of the lower box half and fills it with moist quartz sand. He then places a drying plate on the frame, turns over the assembly, and lifts off the lower box half. The core lying in the sand bed is now ready for transportation to a core oven (Fig. 105).

Making a large core in a turnout core box with loose sides (Fig. 106). In the preliminary operations, the coremaker first prepares a cast frame (grid) for core molding. For this, he bends wire about the contour of the core working cavity and checks it for the right position by inserting the frame into the box. This done, he cleans the box of the adhered sand, wipes its working surface with a kerosene-moistened rag, fills the box with core sand to a depth of 50-70 mm, and rams it.

The coremaker now inserts the clay coated frame 1 into the box 2 and sets up steel pins or hooks 3 (Fig. 106a) to reinforce the protruding and narrow portions of the core. Then he lines the working surface of the box with core sand and rams it into narrow pockets and recesses.

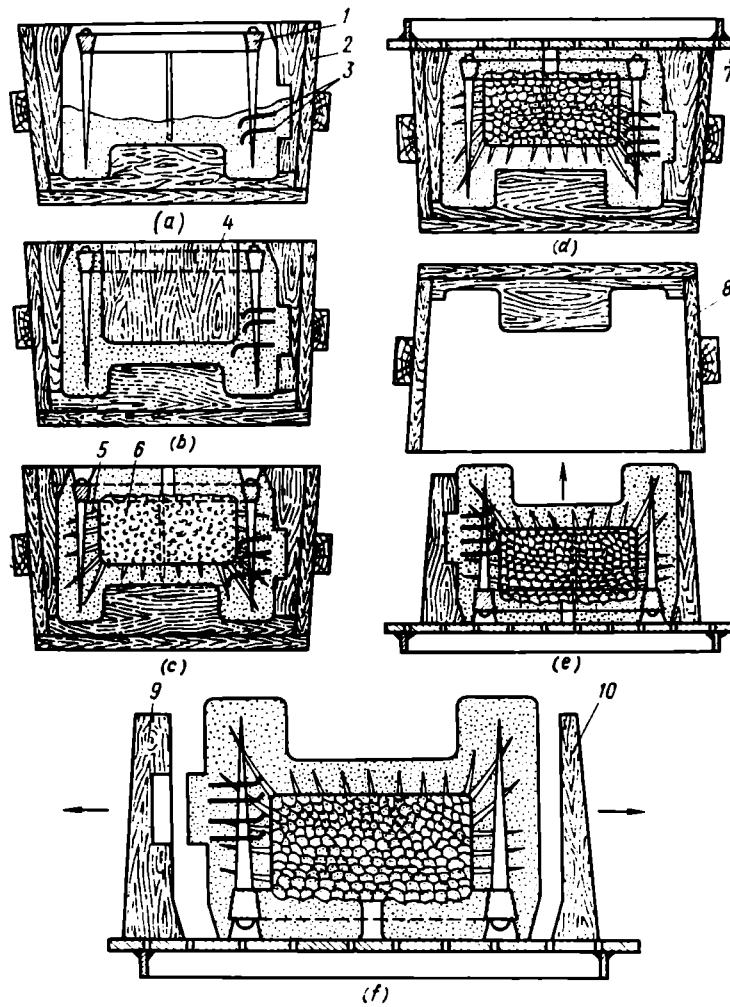


Fig. 106. Making a large core in a loose-frame core box

Next he inserts into the box a wooden piece 4 (Fig. 106b) to form a cavity for coke or coke ash and fills the box around the wooden piece with sand and compacts it.

The coremaker then removes the piece 4, makes vent holes 5, fills the cavity with coke ash 6 and sand and rams the core (Fig. 106c). Using the necessary handling equipment, he places a drying plate 7 (Fig. 106d) on the top and inverts the box.

Further, the coremaker raps the box to facilitate the removal of the upper part 8 (Fig. 106e). This done; he gently takes aside loose pieces 9 and 10 of the box (Fig. 106f). Now he finishes up the core, checks it for compactness, repairs the portions damaged in the core removal operation, rounds off and fillets sharp angles, and inserts metal pins into thin parts and at corners. The finished core is conveyed for drying and then for coating.

6.4. MACHINE COREMAKING

In the mass and large-lot production of castings, cores are made on coremaking machines, which at present are progressively introduced into foundries producing castings in small lots.

Coremaking machines increase the productivity of labor, make easier the work of operators, and produce cores of high accuracy, largely from sands of lowered green strength, which flow readily into deep pockets of the box.

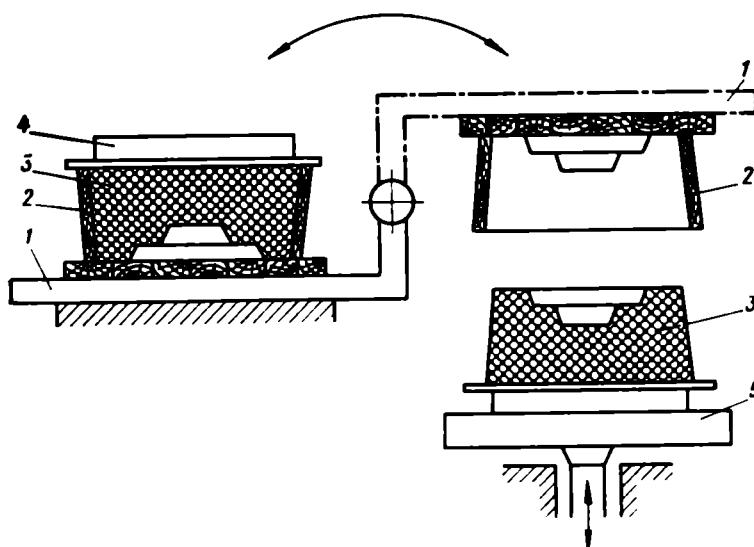


Fig. 107. The scheme of making a core on a core roller jarring machine

There is a variety of coremaking machines available to the foundry, such as core blowing, slinging, jarring, squeezing, core shooter, screw-feed (extrusion) types, and others.

Core jarring machines (core jolters) produce medium-sized and, more rarely, large cores in plain-frame core boxes. Larger cores are made on core rollover and turnover jarring machines.

After ramming the sand by jolting (Fig. 107), a core box 2, fastened to a table 1, together with a core 3 and a drying plate 4 (fixed in position with hand or pneumatic clamps) is rolled over and set up on a receiving table 5. The core 3 is removed from the box as the table 5 is lowered. The table 5 is furnished with a vibrator, which shakes the box and thus frees it from the grip of the core sand. The use of vibrators reduces core damage and enables the production of cores of more accurate size than can be secured in hand coremaking.

Core blowers. Core blowing is a high-productive method of coremaking, which finds wide applications in the manufacture of small and medium-sized high-quality cores of any shape. This method serves as the basis for automatic production of cores.

In a core blower shown in Fig. 108, the compressed air passes through a valve 5 into a head 4 (a container filled with core sand), entrains sand into a box 2 through the holes in a plate 3, and compacts it. The air leaves the box through slit-type or strainer-type vented plugs 6 fitted in the core box walls. The core box 2 is clamped by a mechanism 1 on the plate 3 of the container 4 which is periodically filled

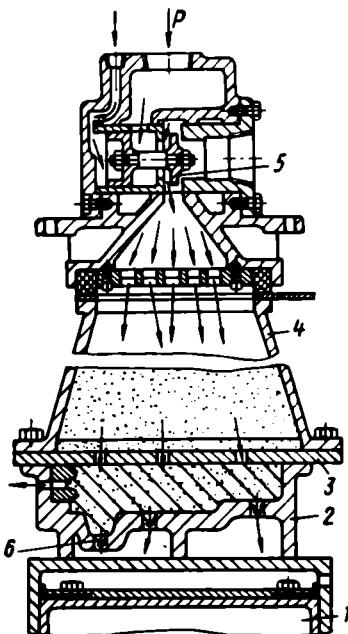
Fig. 108. Making a core in a core blowing machine

with core sand. The machine operates from an air duct which supplies the compressed air at a pressure of not less than 578 kPa (6 kgf cm⁻²).

The core blowing method has a disadvantage in that it calls for core sands of low green strength, 1.96-2.94 kPa (0.02-0.03 kgf cm⁻²). This involves difficulties in core transportation, removal of cores from boxes, and so on.

Choice and positioning of vented plugs in core boxes. Vented plugs allow for the escape of air from the core box and secure the directional motion of the stream of sand and air. Fig. 27 illustrates the design of vented plugs used for core blowers.

In split core boxes of simple shape with a horizontally running parting plane, vented plugs should be arranged in the lower half of the box and evenly spaced one from the other. In intricately shaped core boxes, it is necessary to position vented plugs in the side walls and also in all pockets of the box to make for the desired direction of the



stream of sand and air. In vertically split core boxes, vented plugs should be fixed in the bottom and in the lower parts of the side walls. Since vented plugs wear out fast (holes and slits clog up) and their replacement takes much time, recourse is made to universal plates. A plate of this type used for a few groups of core boxes is provided with vented plugs and sand inlet holes closed by a sliding shutter which can be shifted to open a certain number of holes. From design

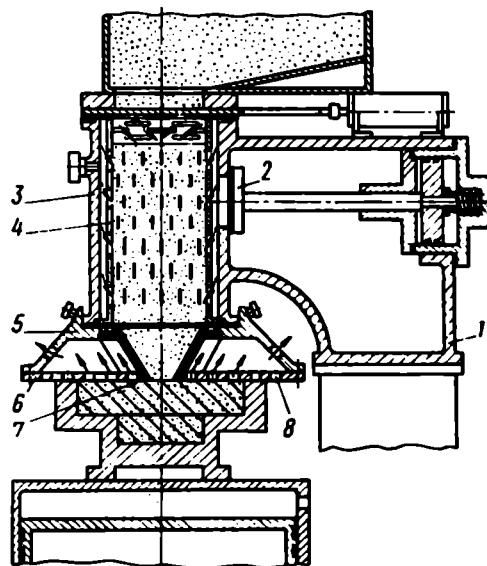


Fig. 109. Making a core in a core shooter

considerations, the diameter of inlet holes can be taken to equal 8 to 12 mm in making small cores, up to 0.3 kg in mass, and 16 to 20 mm when producing large cores.

The number of inlet holes is determined experimentally. One hole of the above dimensions proves sufficient for 50 to 60 cm^2 of the core area in the plane. The core density depends on the ratio of the total cross-sectional area F_{vent} to the cross section of inlet holes, F_{in} . For small cores up to 0.04 kg in mass, $F_{\text{vent}}/F_{\text{in}} = 0.15$ to 0.6; for cores showing a green strength of 14.7 to 19.9 kPa (0.15 to 0.2 kN cm^{-2}), $F_{\text{vent}}/F_{\text{in}} = 0.1$ to 0.9.

Core shooters. The process of sand shooting is a variety of the sand blowing process.

The compressed air passes from a chamber 1 (Fig. 109) into a container 3 of the machine through a quick-acting valve 2 of large cross section. The pressure in the container rises instantly, and the air

forces out a column of sand through a nozzle 7 into the core box. Though the compressed air ceases to pass into the container after closing the valve, the compaction of sand continues as a result of air expansion.

The side walls of a shell 4 set into the container with a certain clearance have slots through which the compressed air acts on the sand and thus decreases its friction against the inside walls and eliminates sand sticking. This feature allows the use of low-fluid sands with high green strength in core shooters.

This process does not form the air-sand stream, and practically only a small amount of air gets into the box cavity during sand blowing. The air escapes into the atmosphere through vented plugs 8.

The air squeezing machines are complete with quick-change heads for making cores of various shapes.

Most of the cores of simple shape are made with the aid of a universal core shooter head shown in Fig. 109. The head consists of a housing 5, plate 6 with vented plugs 8 and changeable nozzles 7. The nozzle orifice can be round, oblong, and cruciform.

Core blowing in hot boxes. Core drying is one of the most time-consuming operations of a coremaking process. The process of production of cores from quick-set synthetic resin-bonded core sands obviates the procedure of core drying in ovens. The essence of the process comes to the following. The core blower forces the quick-hardening sand into the box preliminarily heated to a setting temperature of the binder, which hardens under heat and imparts strength to the core. After a short holding, 2 or 3 minutes, depending on the type of binder and core size, the box can be opened to remove the dry and strong core.

The basic advantages of this production process lie in the following: it excludes kiln drying; ensures high strength and low crumbleness of cores in the dry state, good gas permeability, smooth and accurate surface finish; and provides for easy shake-out of cores from castings. The shortcoming of the process is that it generates the need for a more complex design of core boxes, which adds to the cost of finished products.

It can be concluded from the above that the process is most suitable for cores of the first, second, and third classes used in the mass production of small and medium-sized castings from gray, high-strength, and malleable grades of iron. The process is less adaptable to the production of steel castings since the thermal stability of core sands is insufficient.

The composition of sands for cores produced in hot boxes is given in Table 15. The sands show a low green strength, and therefore it is mainly core blowers that are most suitable for the production of cores from these sands. The core boxes used here differ somewhat in design from conventional core boxes. Since the sand in the core box

hardens at 200-250°C, the box must be sufficiently rigid and capable of standing up to the warpage effect that results from periodic heating and cooling. The material of core boxes must exhibit a high thermal conductivity and increased heat absorption capacity, low thermal expansion coefficient, high strength, and enhanced che-

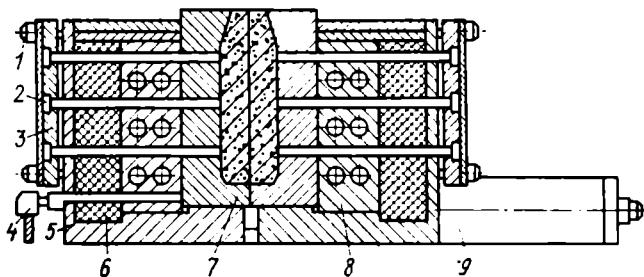


Fig. 110. Core box with built-in heaters

mical stability to binders. Gray iron most fully satisfies these requirements. The workpieces of core boxes are subjected to multiple annealing at 600-650°C to decrease strains that are likely to appear under heat in service conditions. Core boxes have pushers for the removal of cores.

Core boxes can be heated in ovens or stoves. Fig. 110 shows the core box with built-in heaters. The box consists of two halves 7 secured in two casings 5, heating elements 8, plates 3 with pushers 2 and counterpushers, insulating layers 6, and rods 9 which fasten together the castings 5. The plates 3 slide on guides 1 and thus enable the directional movement of pushers. The temperature of the box is controlled by the readings on a thermocouple 4.

The choice of operating conditions for the coremaking process depends on the binder properties, size and shape of the core, and its preset physicomechanical properties.

The optimal heating temperatures for core boxes vary with the nature of binders used. Thus, the binders given below determine the following optimal heating temperatures, °C:

Phenol formaldehyde resins	220
Urea-formaldehyde resins	240
Phenolic alcohols	220-260
Furan-base binders	230-240

The time of holding of a core in the box ranges from a few seconds to a few minutes and depends on the binder properties, wall thickness of the core and its shape.

To exclude sticking of the core sand to the box, its working surface is coated with a parting composition which is a solution of 3% synthetic heat-resistant rubber in white spirit. The solution is sprayed on to the box surface heated to 80-100°C, and the coat is dried for 10-15 min. The box used for the subsequent production of cores is then coated at the operating temperature. The durability of the coat is 20 to 50 cores.

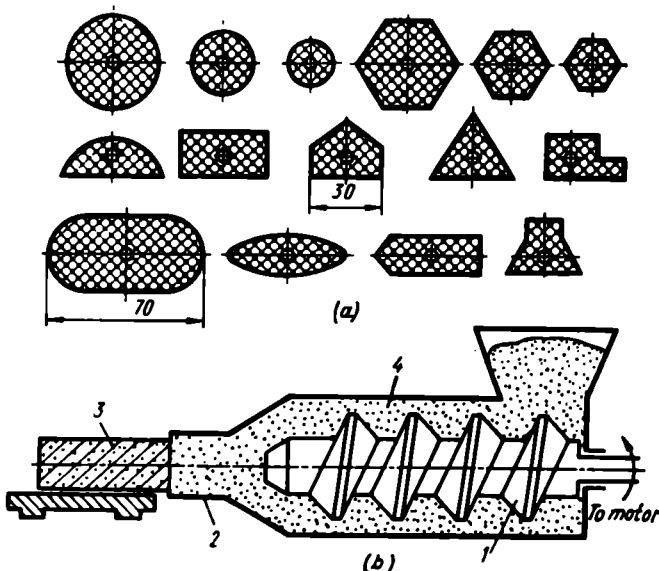


Fig. 111. Making cores on an extrusion machine
(a) cross sections of cores; (b) scheme of the machine

Making cores from synthetic resin-bonded cold-curing mixtures. The coremaking process that uses these mixtures has all the advantages of the process of core production in hot boxes. Moreover, the mixtures do not require heat for hardening, which permits using core boxes of a simpler design. The binders here are synthetic resins of B-1 class and others. The hardening catalysts are organic and inorganic acids such as benzenesulfonic, orthophosphoric, and nitric acids. The mixtures with these binders have a small life and need be prepared directly on the coremaking site in fast-speed paddle mixers complete with automatic batchers. The components are charged into the mixer in the follow sequence: the sand, hardener, and then the binder. The time of mixing is 15 to 20 s. The ready mix is poured into boxes where it is held for 2-15 min until its compression strength reaches 294-490 kPa ($3-5 \text{ kgf cm}^{-2}$). The core is then removed from the

box and allowed to stand in the air for 30-120 min. As a result, the core acquires a strength of about 785-1 180 kPa (8-12 kgf cm⁻²). The mixes of the composition given in Table 16 also find use for the production of cores.

Synthetic resin-bonded mixtures give off acrid odor, and therefore the coreroom must be properly ventilated.

Extrusion machines (Fig. 111b) produce small cores of uniform cross section whose shape and size (Fig. 111a) is determined by the shape and size of the die orifice. Core sand 4 is extruded by a screw 1 or piston through a replaceable die 2 onto the plate. The sand goes out in the form of a continuous core 3 which is cut to the desired lengths after baking. The core prints of cores are then ground if necessary. The machines are simple in design, reliable in operation, and highly productive.

6.5. FINISHING, INSPECTION, AND STORING OF CORES

Before transporting the dried cores to the store, they are subjected to additional treatment: burr trimming, sealing for correcting small defects, so on. The cores are trimmed off with an emery stone, file, wire, hard rubber, and emery paper.

Grinding of cores. In mass and large-batch production, cores are ground on rotary grinding machines in special jigs (Fig. 112). The grinding allowance for cores is 1.5 to 2 mm. Grinding gives smooth surface finish and ensures accurate dimensions of the core after mating the core halves. The grinding disk rotates at a maximum speed of 8 rpm, the minimum rotational speed being 4 rpm. The machine output is in the range of 700 cores per hour.

Burrs are trimmed off manually on benches, or on conveyors in mechanized shops.

Assembling of cores. In cementing a few cores, one should serve as a reference block, a base, for the others. The position of cores is checked with template gages, feeler gages, or measuring tools. To keep the cores from shifting one relative to another, it is well to fix them in position with spacers laid in between, which are then taken off after glue drying. Cores are usually set in the mold separately, one at a time. This procedure takes a lot of time, let alone the fact that an intricately shaped core is often impossible to place in the mold at all. In such cases the cores are preliminarily assembled into blocks.

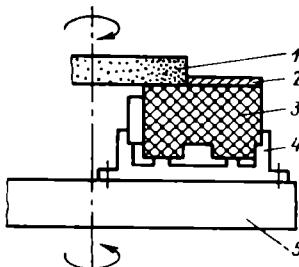


Fig. 112. Scheme of core grinding

1—grinding disk; 2—grinding allowance; 3—core; 4—jig; 5—grinding machine table

fastened together with a cement, and then the core assembly is put into the mold cavity. The cement is applied with a brush or special injector.

An example of the simplest type of core assembling is gluing together the halves of a cylindrical core (Fig. 113). The coremaker places a core half 1 with its flat face upward in a fixture 2 and then sets on the top the other half and laps one half against the other.

The size of the core box allows for lapping, the allowance being equal to 0.5-1 mm. Afterlapping the core and checking it with a template gage, the core-maker takes off the upper half and puts it aside.

He now applies a cement to the flat face of the lower half in

two streaks so that after jointing the core halves the cement can spread over the entire parting surface, but not flood the vent channel or run outward.

Assembly jigs provide for accurate core gluing. Fig. 114 shows the core set for a borer headstock, built up in the jig before setting it

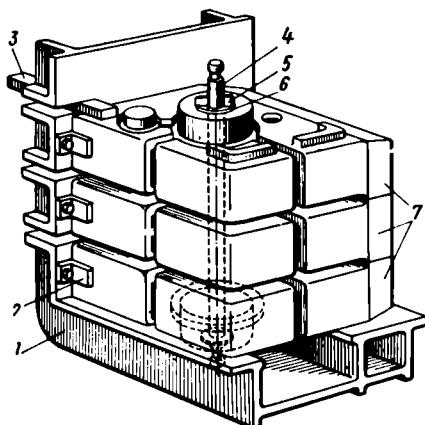


Fig. 114. Core set for a borer headstock

1—jig-tilter; 3—back square; 3—check plate; 4—steel tie rod; 5—wedge; 6—washer; 7—core elements

into the mold. After cementing the cores and sealing the seams with putty, the core assembly is slightly dried. Additional drying is not required for cores glued warm, but is certainly necessary for repaired cores (to dry up the core sand applied to the areas ruptured in the assembly operation) and also for cores which are given a coat of wash

when being cold. The time and temperature of drying depend on the mass of cores, as is clear from Table 24.

Table 24
Drying Schedule for Cores After Gluing

Core mass, kg	Time of drying, min	Temperature, °C	Core mass, kg	Time of drying, min	Temperature, °C
To 5	10		50-100	12-15	
5-20	12	200-220	100-200	15-20	220-250
20-50					

Cores are baked in small driers, chamber ovens, or continuous units equipped with charging and discharging conveyors. The dried cores are delivered to the store or to the site for completing core sets, and then to the mold assembly section.

Core inspection. The finished cores are examined for surface defects and checked for dimensional accuracy. Visual inspection can reveal the degree of sand compaction, surface condition, relative positioning of core halves, and also the accuracy of assembling, seam sealing, the quality of protective painting and drying. The dimensions are checked with measuring tools, various template gages, control clamps, and jigs. In checking the core size with a template, the gap between the core and the template is determined by means of a feeler. The same procedure can be performed using a go- and a no-go-template gage (Fig. 115). The core is considered fit for use if the go gage that determines the maximum core size smoothly passes over or into the core, and the no-go gage does not.

Storing of cores. The cores which have passed quality control are conveyed to the store where they are laid on felt-lined shelves. Small cores are accurately placed on the bottom of metal boxes and, sometimes, spaced from one another with strips of thin felt. The cores must be stored in dry premises and kept there for not more than 5-7 days, because prolonged storage causes disintegration of cores.

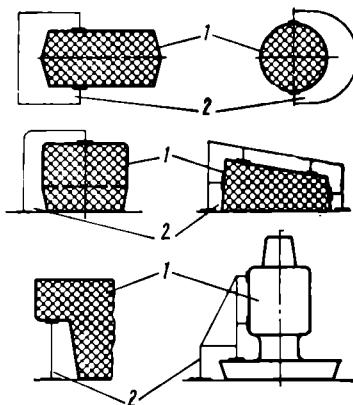


Fig. 115. Template gages for checking the size of cores
1—core; 2—template gage

6.6. MOLD AND CORE DRYING

This procedure is aimed at increasing the gas permeability and strength of sand molds and cores, decreasing their gas evolution capacity, and, in the final analysis, improving the quality of castings. The drying schedules for various groups of sand molds and cores are determined experimentally.

The drying process may conditionally be divided into three stages. At the first stage the entire bulk of a sand mold or core heats through. Because the moist sand has a much higher thermal conductivity than the dry sand, it is necessary, where possible, to strive to keep the moisture from leaving the core at this stage, that is, not allow it to evaporate too fast. The operating temperature of the oven should be raised gradually. The moisture present in the oven atmosphere and the moderate temperature of heating decrease the rate of moisture evaporation from the surface of a mold and aid in its uniform heating.

At the second stage, it is necessary to raise the temperature fast to a maximum value and hold cores at this temperature for a certain period of time. The sharp increase of the oven temperature at this stage speeds up the evaporation of moisture and encourages a fast inflow of moisture from the bulk of the core to its surface. Measures should be taken to evacuate quickly the moisture-containing gases and intensively supply fresh and dry furnace gases into the oven.

At the third stage, molds and cores cool down to a discharging temperature. The pieces also dry out at this stage at the expense of the heat they have stored.

The period of drying of molds and cores depends on many factors (drying temperature mass of pieces, conditions of heat transfer in the oven, and so on). The time of drying, usually determined from experiments, varies from a few minutes to a few hours.

Proper drying of molds and cores calls for the following operating conditions: the temperature in the oven chamber should rise gradually to a maximum permissible value; the variations of temperature in various zones of the oven should not exceed 10-15°C; the gases in the entire volume of the oven should move uniformly at a speed of 1.8-2.2 m/s.

During baking of cores made from sands with oil binders and their substitutes, the cores oxidize and polymerize as they give off moisture.

The oxidation process involves the rupture of bonds between carbon atoms that enter into the oil composition and the capture of oxygen atoms. Polymerization tends to enlarge molecules. Chemical processes attended by the expulsion of certain components that evolve gases cause the oil to transform into a thick and sticky mass (linoxyn); the strong films of linoxyn envelop sand particles and thus bind them together.

The oxidizability of oil grows with the additions of salts of man-

ganese and lead. The oil begins to oxidize at 110-140°C; oxidation proceeds very quickly at 170-230°C so that the oil picks up 20 to 30% by mass oxygen. The heat evolved during the process also accelerates oil oxidation.

After heating of cores, made from sands with artificial thermosetting resins, and evaporation of the moisture, the resins become infusible and insoluble in water. Thermosets form strong films on sand grains during core baking. Dried cores feature insignificant hygroscopicity. The drying temperature of cores with these binders is 150 to 160°C.

In drying of cores prepared with lignin, dextrin, and molasses, bonding forces appear between the molecules as the water evaporates and binder particles come closer together. In cores prepared with a starch-base binder, moisture evaporation is attended by paste formation at 60 to 80°C. Starch-bonded sands are dried at 165 to 190°C. In molasses-bonded sands, sucrose forms after water evaporation; in lignin-base sands, heating causes the formation of a resin of good sticking ability.

Cores made with such bonds as clay and cement are subjected to baking at 350-400°C; bentonite-bonded sand cores are dried at 200°C.

Apart from oven drying, in use is the method of drying cores and molds in the air heated to 40-100°C. Hot air curing forms a strong crust on the surface of molds and cores.

Hardening of cores made from liquid glass-bonded sands. In preparing these sands in millers, sand grains become coated with a thin film of liquid glass (sodium silicate) during mixing. While blowing the gas carbon dioxide through the rammed sand, CO₂ dissolves in water and partially reacts with it, forming the carbonic acid.

The acid and water react with sodium silicate to form silica gel which acts as a strong bond between the sand grains.

The cores made from liquid glass-bonded sands are dried at 200-250°C. The dried cores are superior in strength to the cores bonded only by the CO₂ process.

Drying of molds. Molds are either dried completely or to a certain depth. Most of the large molds are skin dried to speed up the drying procedure. The molds for particularly important castings and also the small, medium-sized, and large molds for thin-walled and intricately shaped castings should be dried through.

Various methods are available for surface drying of molds to a depth of 10 mm and over. The means used for the purpose are inflammable alcohol or benzine-soluble dyes, gas and kerosene torches, portable driers, and infrared lamps of 250-500 W.

In Fig. 116 is shown the scheme of a drying installation with porous brick-panel gas burners for skin drying of molds measuring 1 500 × 1 000 mm. Molds made from unit sand with a moisture content of 4 to 4.5% and a green strength of 390 to 490 kPa (0.4 to 0.5 kgf cm⁻²) are first coated with an antipenetration wash and then

delivered on the roller conveyor to the installation. Drying the molds for 10 min by the heat of brick-panel gas burners produces a dried skin 8 to 12 mm in thickness.

The optimal schedules for surface drying of molds are given in Table 25.

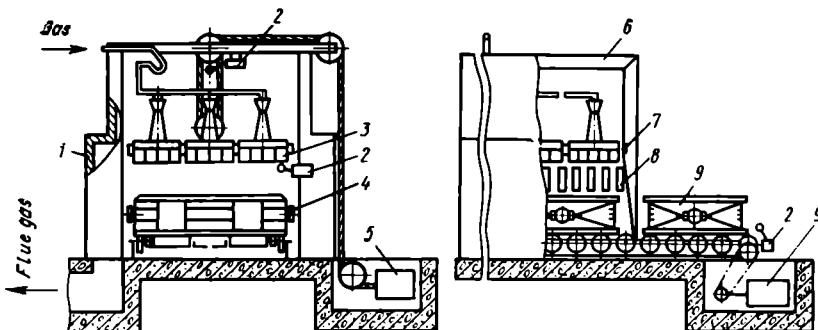


Fig. 116. Installation for skin drying of molds

1—thermal insulation; 2—limit switches; 3—porous brick-panel gas burners; 4—half-molds; 5—drive for lifting the frame with burners; 6—metal casing; 7—movable frame; 8—side suction fans; 9—roller conveyor drive

There is a variety of ovens for complete or through drying of molds. Most widespread are the ovens of periodic action (batch-type stoves). These include stoves having a compartment for charging and unloading at one end only, bogie-type stoves with doors at both ends, and pit drying stoves in which a drying compartment (pit) is located below the floor level.

Bogie-type drying stoves are batch-type drying chambers into which molds are introduced on carriages. Drying pits are charged by means of an overhead crane, for which purpose the pit top is made removable, from separate sections.

Batch-type drying stoves operate on solid, liquid, and gas fuel. They are also suitable for drying of cores.

Table 26 gives the drying time for molds of various dimensions.

The use of quick-drying facing sands enables cutting down the drying period to a few minutes.

Core facing and drying. Antipenetration washes, whitenings, and dusts serve to prevent burning into the sand. They are applied to the surface of cores by a variety of methods: by dipping, spraying, brushing, and dressing (special pastes). An antipenetration paint must have a definite viscosity. The coat of too thick a wash may crack and come off from the core surface, while an excessively liquid wash may cause metal penetration.

To give a single coat of wash to a core, it is advisable to coat the core before drying since the surface lets in the wash more readily in

Table 25
Optimal Schedules for Skin Drying of Molds

Casting	Mass of casting, kg	Molding sand	Wash	Schedule of drying			
				Appliance	Temperature, °C	Duration, min	Dried skin, mm
Small	100	Common, clay bonded	Graphite-base, applied before drying	Burners	—	2-3	1-3
Medium	100-1 000	Unit and facing, with binders of B-2 and B-3 classes			260-290	10-30	8-12
Large	1 000-5 000	Common, clay bonded	Surface strengthening, applied before drying; and graphite-base, applied after drying	Portable driers	280-320	40-60* 70-80**	15-20 18-25
		Sodium-silicate bonded	Graphite-base, applied before and after drying		270-300	20-35* 45-70**	18-20 20-25

* For molds with cavity depth up to 400 mm.
** For molds with cavity depth up to 1 000 mm.

Table 26

Drying Period for Molds

Overall size of mold or flask, mm	Time, h, for casting	
	iron and nonferrous alloy	steel
To 500 × 400 × 250	4-6	6-8
1 000 × 800 × 400	6-8	8-12
3 000 × 2 000 × 500	8-12	12-16
5 000 × 3 000 × 700	12-24	16-24
Above 5 000 × 3 000 × 700	24-36	24-36

the moist state. The wash penetrates into the pores between sand grains and thus provides a smooth finish and strong antipenetration coating. Large cores for thick-walled castings are first coated cold before drying at 120 to 150° and then given a second coat while hot, as soon as the temperature of cores drops to 50-70°C. At a higher temperature the wash spreads unevenly over the core surface. Cores made from liquid glass-bonded mixes are coated with anhydrous self-drying facing materials. After coating, the cores require standing in the air for 2-2.5 h.

Large cores for steel castings are dressed with a paste applied in a layer of 3 to 5 mm in thickness, which is smoothed over with a trowel. The cores are then reinforced with metal pins and allowed to dry in hot air. Coating strengtheners such as lignin, liquid glass, and others, applied to the surface of cores before wash coating, help decrease the number of castings scrapped as a result of scabs.

After drying, the strengthener forms a strong skin 2-3 mm thick on

Table 27

Drying Period for Cores

Binder	Drying tem- perature, °C	Time, h, at core wall thickness, mm		
		to 100	100-200	above 200
Organic	160-240	0.75-1.5	1.5-3.0	3.0-7.0
Clay	300-350	1.0-2.0	2.0-5.0	5.0-24.0
Liquid glass	200-250	0.75-1.0	1.0-2.0	2.0-5.0
Thermosets	300-400	0.3-0.75	0.75-1.5	—

the core surface. Table 27 gives the core drying time according to the size of cores and binders used.

Foundries engaged in the mass production of castings use multiple-path, horizontal, conveyor core-baking ovens.

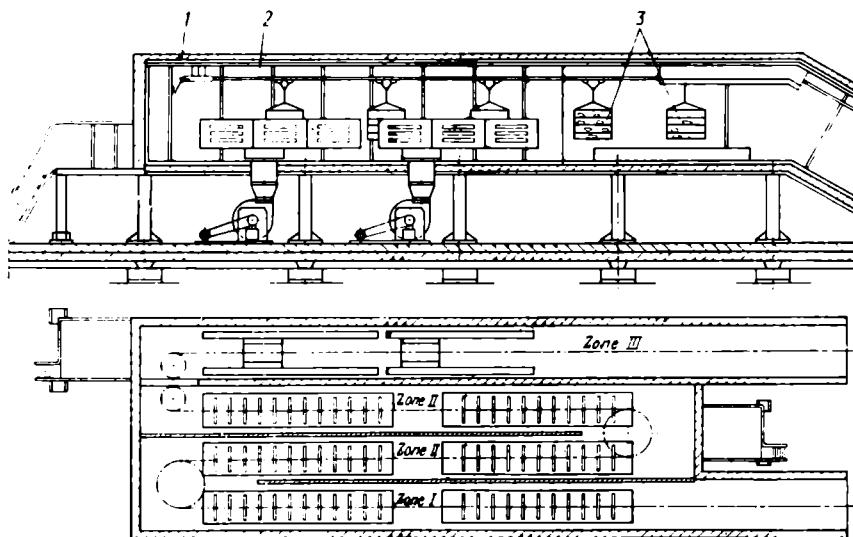


Fig. 117. Scheme of a horizontal continuous conveyor-type four-path oven for core drying

Figure 117 illustrates the scheme of a horizontal continuous four-path oven for drying small and medium-sized cores. The oven housing 1 rests on columns. Inside the oven, an endless chain conveyor 2 moves under the roof for transporting cores placed on special core racks 3 suspended from the chain. The oven has three passageways for the zones of heating (I), drying (II), and cooling (III).

One branch of the conveyor passes through the heating zone, two branches run through the drying zone, and one branch goes along the cooling bay. The first zone is 37 m long, with a heating temperature of 40 to 80°C, and the second is 83 m long with a drying temperature ranging from 200 to 235°C depending on the core binder used. The time of drying is 110 to 120 min at a conveyor speed of 1 to 1.5 m/min. The oven turns out about 3 000 dried cores in an hour.

Vertical continuous ovens are used for drying small cores after cementing, repairing and coating. An oven of this type operates in the following manner. In a vertical drum set up on the foundation, a vertical conveyor moves with rack-type containers. Green-sand cores are placed on the racks through a hatch or door. The containers suspended from the conveyor go up into the zone of higher temperatures and then down to the discharge door. The burner is located inside the oven above the charging and the discharging door. The oven operates on gas or black oil and gives 0.8 to 2.5 tons of dried cores per hour.

Chapter 7. MOLD ASSEMBLY AND FASTENING

7.1. MOLD ASSEMBLY

Assembling of molds is an important process which requires of assemblers much care and skill. Mold assembly involves a cycle of operations which include preparing half-molds and cores for assembly, setting in cores (commonly in the drag), checking the position of cores, fixing in place flowoff and pouring cups, closing the mold and fastening the core to the drag, or weighting the mold.

The half-molds and cores delivered to the assembly are thoroughly examined to reveal the damaged or defective members, if any. Before assembly, the mold cavity is blown off by an air jet to eject loose sand particles and foreign matter.

Cores are set into molds in the sequence specified in the assembly drawing or process chart. In performing this operation, one must take care that the core prints of cores seat correctly in the impressions. It is impermissible to file the core print to secure a fit if it does not enter the core-print seat for some reason or other. Only in particular cases (in piece or small-lot production) is it allowable to adjust a fit for core prints, using template gages. The position of every core in the mold and also its position relative to other cores are checked with template gages.

The space width between the cores and mold walls or only between the cores, which makes for the casting walls of the desired thickness, is checked with thickness gages. In the conditions of piece production, recourse is made to check closing of molds if they are too complex and do not allow for direct measurement of the space width with gages and measuring tools after coring up. Before closing the mold, pieces of loam (thickness pieces) are applied to the surface of half-molds and cores in certain places. Locking the mold causes the loam pieces to compress under pressure to a thickness equal to the clearance between the mold and core faces. After opening the mold, it is now necessary to measure the thickness of the loam pieces taken from the mold and thus determine the possible thickness of the casting walls.

Cores are usually set in the drag and secured in position with core prints, but sometimes they are fastened to the cope. The coresetting operation requires particular care on the part of assemblers because an unreliable fastened core may tear away from the mold, break up and damage the mold, or even lead to a mishap.

Sometimes it is impossible to provide sufficient support for a core in the mold being poured. In such cases the core is supported with rigid metal pieces, called chaplets (Fig. 118), placed between the core

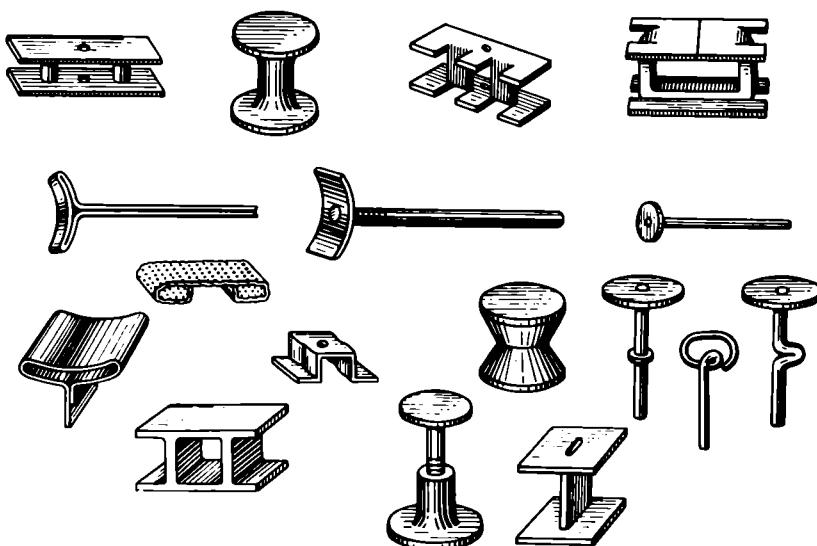


Fig. 118. Types of chaplets

and the mold face. The height of the chaplet is taken equal to the wall thickness of the casting. The alloy chosen for chaplets must conform to the molten alloy poured into the mold in order to effect proper fusion. In casting iron or steel pieces, the use is made of chaplets from tin plate and low-carbon steel.

The surface of chaplets must be clean, without traces of corrosion, moisture, and oil. Chaplets are shot peened and then tinned before use. Clean chaplets fuse well with molten metal and do not cause the formation of holes and discontinuities. It is however undesirable and even, sometimes, impermissible to use chaplets for castings destined to operate under the pressure of a liquid or gas.

7.2. MOLD FASTENING AND WEIGHTING

The molten metal poured into the mold exerts a force on the mold walls in proportion to its density and the height of the metal column in the mold. The pressure of molten metal can be strong enough to lift the cope and thus form a gap at the parting plane between the cope and drag, through which the metal will flow out. To prevent the cope from floating, the cope and drag are fastened together with bolts, clamps, wedges, or the assembled mold is weighted by placing a pouring weight onto the top surface of the mold (Fig. 119). If the pressure of metal is expected to be very high, the mold is set into a

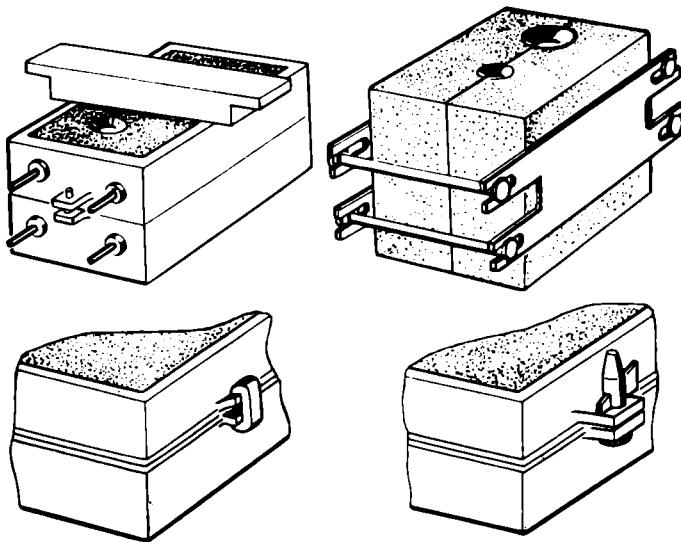


Fig. 119. Methods of fastening half-molds

permanent pit. The mold is ready for pouring after ramming the sand at its side and weighting.

In order to calculate the mass of a pouring weight and thus choose the right fastening means, we must know the force at which the

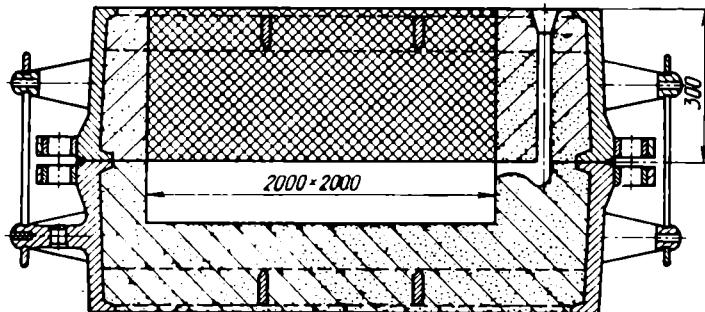


Fig. 120. Calculating the mass of a pouring weight

metal acts on the drag. This force is equal to the mass of an imaginary column of metal in the cope, the column height being equal to the distance from the casting top to the upper level of the pouring basin. In Fig. 120, this hypothetical column of liquid is crosshatched.

Let us calculate the mass of a weight required for the mold shown in Fig. 120 and thus choose the right fastening means.

Calculating the mass of a weight for the mold. For this, we must determine the force of metal on the cope. Considering the density ρ of molten iron being 7 kg dm^{-3} , this force is

$$P_m = Fh\rho = 20 \times 20 \times 3 \times 7 = 8400 \text{ kgf (84 kN)}$$

where P is the plan area of the casting, and h is the head of melt.

In calculations, we should take a somewhat larger value of P_m to include a margin for the dynamic action of the metal being poured, which may cause mold

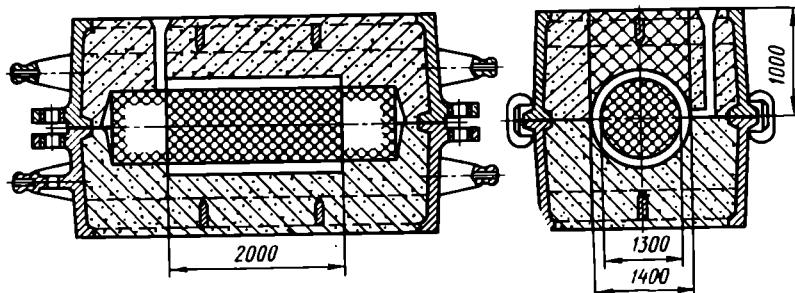


Fig. 121. Calculating the force of molten metal on a cope

opening, and for the nonuniform distribution of metal pressure over the cope area.

Calculate the force of metal of a cylindrical casting (tube) on the cope in gating the mold at the parting plane (Fig. 121).

The force of metal on the internal surface of the mold is equal to its mass. The outer diameter d of the tube is 1400 mm, the length l is 2000 mm, and the head of the metal $h = 1000$ mm. So,

$$P_m = \left(dlh - \frac{1}{2} \cdot \frac{\pi d^2}{4} l \right) \rho = \left(14 \times 20 \times 10 - \frac{1}{2} \cdot 0.785 \times 14^2 \times 20 \right) 7 = 8820 \text{ kgf (88.2 kN)}$$

The molten metal envelops the core on all its sides and tends to lift it. The upward (buoyant) force on the core is equal to the mass of liquid displaced by the core:

$$P_c = \frac{\pi d}{4} \cdot l \rho = \frac{3 \times 14 \times 13^2}{4} 20 \times 7 = 18590 \text{ kgf (185.9 kN)}$$

where d is the inner diameter of tube, equal to 1.3 m.

The core lifting force acts on the cope. The total force of metal that tends to lift the cope is

$$P = P_m + P_c = 8820 + 18590 = 27410 \text{ kgf (274.1 kN)}$$

To determine the force which the fastening means have to stand up to, we must subtract the mass of the cope and increase the found value by 30 to 40% to allow for the hydraulic impact taking place during pouring.

Chapter 8. DESIGN OF CASTINGS, MOLDS, AND CORES

The basic task set in developing a casting process lies in selecting the right production techniques which ensure high technical-and-economic indexes at all the stages of the production process and also the requisite quality of cast parts in service. In estimating a particular production process, one must consider the cleaning and machining costs as well as the cost involved in the manufacture of castings in the foundry. The right approach here is to search for the ways of cutting down the machining allowances, simplifying the molding process, and fully utilizing the capacities of the available machinery.

8.1. DESIGN OF CASTINGS

A cast part must have such a design as to ensure a high level of its working characteristics (strength, rigidity, tightness, and corrosion resistance) at a given mass and shape of the part. Also, the part design must take into account the casting techniques and machinery available; in other words, the part must be readily producible and machinable.

The main feature of the casting process is that the molten metal poured into the mold contracts as it cools and solidifies, that is, the metal undergoes phase transformations accompanied by its shrinkage in volume and appearance of shrinkage defects such as contraction cavities (pipes), porosities, hot tears, and also of stresses. Since the metal poured into the mold cavity interacts with the mold, the casting may develop surface defects such as blows and burning-on. To obtain a sound casting, the mold should have definite properties described in Ch. 1. Besides, the mold should take a minimum of time and labor for its manufacture. In designing castings, one should follow the principles set forth below.

1. The pattern for a casting should be so designed as to effect the maximum possible savings in labor and materials spent on its manufacture. For this, the casting must be compact in design, have not protruding elements, whenever practicable, and represent a combination of simple geometrical bodies whose shapes predominantly feature flat surfaces and straight lines. This also simplifies the patternmaking process and reduces the cost of the pattern set.

The pattern elements for bosses, lugs, and flat protrusions should be made so that they cannot hinder the removal of the pattern from

the mold. Thus the pattern elements for lugs shown in Fig. 122a will impede the withdrawal of the pattern. They have to be made detachable or the lugs be formed with the aid of cores. The lugs shown in Fig. 122b are more readily producible.

2. The design of a casting should provide for ease of manufacture and assembly of the mold; the mold construction should require a minimum of cores of the simplest shape possible. Large-sized intri-

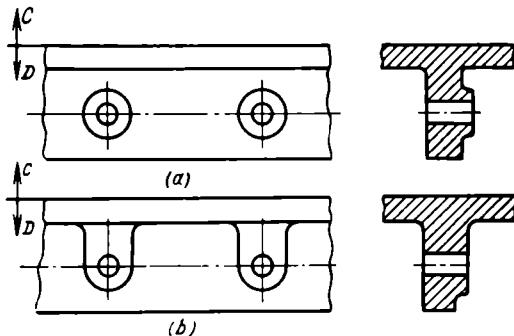


Fig. 122. Variants of forming bosses on castings

cately shaped parts should be divided into simple parts which are easier to cast and then weld together or connect with bolts (to form a weld-and-cast structure). For example, the molds for castings given in Fig. 123b will call for a curved mold joint, which involves coping-out, the use of a pattern match or a follow board. The joint will become simpler if we change the casting design and use instead the design of castings shown in Fig. 123a.

3. The cavities in castings should have extensions roomy enough to receive the core prints of cores. Adjacent cavities should communicate through the openings to provide the seats for core prints, thereby securing a steady position of the core in the mold and, hence, producing the cast part of good dimensional accuracy (Fig. 124a). It is undesirable to support cores with chaplets (Fig. 124b) since they sometimes do not weld enough with the metal being cast.

4. The walls of a casting should be made uniform in thickness, whenever feasible, because shrinkage defects may arise in the thickened portions, such as porosities, pipes, and cracks.

A casting should not have sharp angles or wall sections which abruptly pass into thin walls. The portions at the intersection of walls of various thickness should form smoothly curved junctions (Fig. 125). If ribs of thickness δ share many common areas of diameter d , the possibility exists for hot metal accumulation at the junctions. The right positioning of ribs, as shown in Fig. 126, can safeguard against this undesirable occurrence. The mass of a casting should be as small

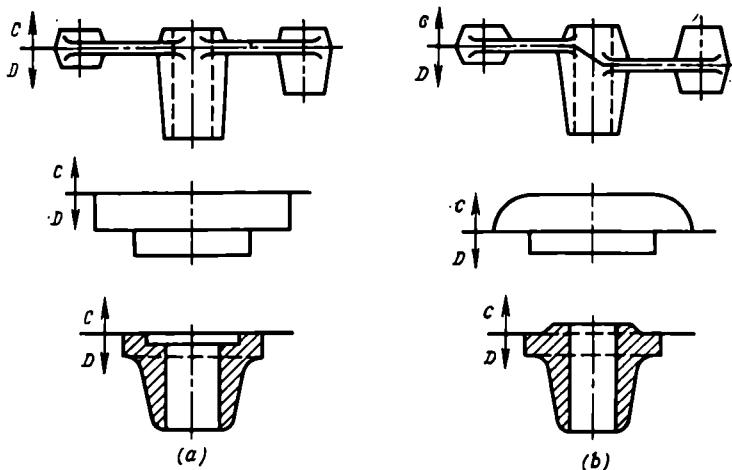


Fig. 123. Correct (a) and incorrect (b) types of the design of castings

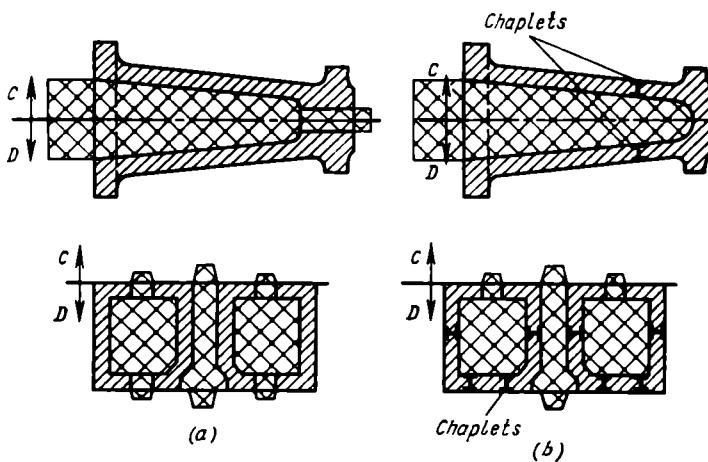


Fig. 124. Correct (a) and incorrect (b) position of cores in castings

as possible to ensure metal economy. The metal saving approach should always be a guiding principle for the designer, except for some particular cases.

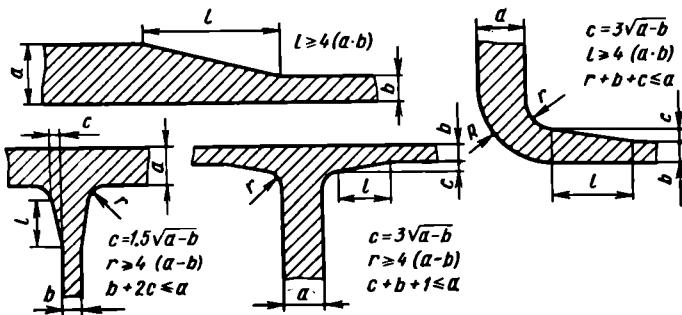


Fig. 125. Types of junction of walls varying in thicknesses

5. The design of a cast part must take into account the casting properties of the alloy being cast.

Gray iron has good casting properties. The structure of gray iron is more dependent on the rate of cooling than that of other grades.

A change in the iron structure brings about changes in the mechanical properties of iron, its machinability, durability, corro-

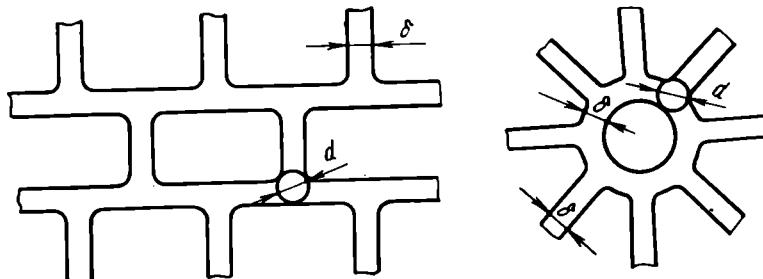


Fig. 126. Advisable layout of strengthening ribs on castings

sion resistance, and other working properties. If the metal cools fast, all the carbon in the thin walls of castings proves to be in the bound state, forming the cementite, Fe_3C . This structure component of high hardness is not amenable to machining. The defect of this type in gray-iron castings is called hard spots. In the thick walls of the same casting the metal solidifies slowly, which results in the struc-

ture of low hardness. So, the need for the uniform thickness of walls in gray-iron castings acquires a particular importance.

High-strength grades of iron show decreased fluidity and enhanced shrinkage, which factors should be properly considered in designing the castings.

The low fluidity of steel causes difficulties in producing thin-walled castings of large lengths. Since steel has a high shrinkage, blows, cracks, and porosities may appear in the thickened sections of castings, at the junctions of walls, and in bosses. Risers placed on the top of steel castings help eliminate these defects. At the junctions of walls of various thickness, special reinforcing ribs are provided to exclude the formation of cracks in the castings. The ribs are then cut off in the fettling operation.

Aluminum alloys are rather fluid materials, but they are not free of such defects as gas holes and shrinkage porosities, especially in massive members. For this reason, it is advisable to produce aluminum castings with thin walls of uniform thickness.

Magnesium alloys are inferior to aluminum alloys in casting properties. They are subject to porosities, and therefore the thick sections cast from these alloys show poorer mechanical properties than thin members.

Tin bronzes have satisfactory fluidity, but since they solidify long, the metals develop shrinkage voids which lower the plasticity and tightness of castings. A decrease in the wall thickness of castings increases the rate of solidification and thus aids in improving the properties of castings.

Tin-free bronzes show enhanced shrinkage, for which reason the casting design should provide for risering of castings.

6. The construction of a casting should make for ease of cleaning and fettling after the shakeout operation. The outer contour of the casting should be free of deep blind pockets and recesses. The cavities should have openings of sufficient size to facilitate stripping.

7. The locating surfaces on castings should afford convenience for machining.

8.2. DESIGN OF MOLDS AND CORES

In devising the molding process, the designer must handle the following tasks: choose the right method of molding, decide on the position of the casting and mold during pouring, specify the type of mold joint, define the ways of setting the cores in the mold, select the appropriate type of gating system and make necessary calculations, work out the casting drawing, determine the overall dimensions of molding boxes, and properly locate patterns on the pattern plate.

The technologist-founder must then thoroughly study the casting design together with the designer and make design corrections, if

required, aimed at improving the manufacturability of the cast part. Thus, it may be found necessary to increase the radii of fillets, make the walls more uniform in thickness, and eliminate abrupt narrowings at the places where massive members pass into thin walls.

When choosing the position of the casting in the mold, the designer should dispose most responsible members in the drag where the metal turns out to be denser. Besides, he should abide by the following rules:

1. The position of the casting in the mold must ensure directional solidification of metal.
2. The members destined for machining should be located at the bottom, in the vertical or inclined positions during pouring and metal solidification.
3. Cylindrical castings whose outside and inside surfaces are subject to machining should have a vertical position during pouring.
4. The casting surfaces which serve as datum planes in machining should lie in one half-mold.

Figure 127a shows the method of inclined pouring which ensures good tightness of metal at a minimum of metal waste for risers. The top method of gating (Fig. 127b) of steel and iron bushes, hoisting drums, and other parts provides for pressure-tight side walls and correct feeding of castings during solidification.

Figure 127c illustrates the method of pouring of a thin-walled iron gear case; the flange to be machined lies here in the parting plane as the high fluidity of iron excludes misrun (short run). In making this part from steel, the position of the casting should be reversed to have its flange facing upwards in order to guard against short run at the bottom and the formation of shrinkage voids which may result in a leaky gear case.

Figure 127d shows the method of partial-reversal pouring of the bronze disc for a thrust bearing of cone crushers. This partial-reversal manipulation gives a high-quality casting surface.

In working out the mold joint, the designer should keep in mind the following instructions:

1. It is preferable to dispose the entire casting in the drag if the casting construction permits doing so. This helps rule out mismatch (cross-joint).
2. It is desirable that the mold joint can lie in the horizontal plane during pouring.
3. The mold joint should allow for free removal of the pattern from the mold and easy setting of cores. Also, the joint should satisfy the condition according to which the process of production of a casting must be consistent with the machining process chosen for the casting.
4. The mold should have a minimum number of cores or no cores at all, if possible; it is advisable to use projection cores.
5. The chosen mold joint should enable easy sand compaction

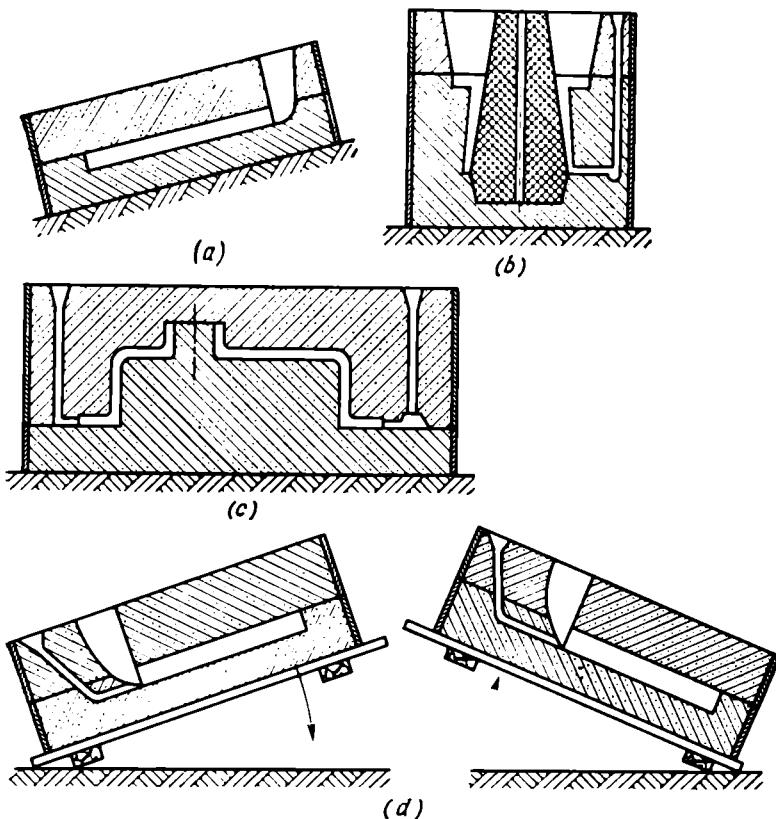


Fig. 127. Examples of correct positioning of molds during pouring

and mold assembly, reliable positioning of cores and checking for the right location in the mold.

6. When molding a casting in the foundry floor, the main elements of the casting should be arranged only in the drag (Fig. 128).

In machine molding, the choice of the mold joint is dictated by the type of molding machines available.

Projection cores should not be too high, otherwise a part of the mold may break away, causing what is called a drop in the mold. Practice has established the following dimensional ratios for projection cores (Fig. 129): $H \leq D$ for drag cores and $H \leq 0.3D$ for cope cores. In hand molding, these ratios should be about half as large in value. At higher values of H/D , use is made of cores.

When determining the contours of cores, it is necessary to consider the ways of facilitating the coremaking process so as to turn over

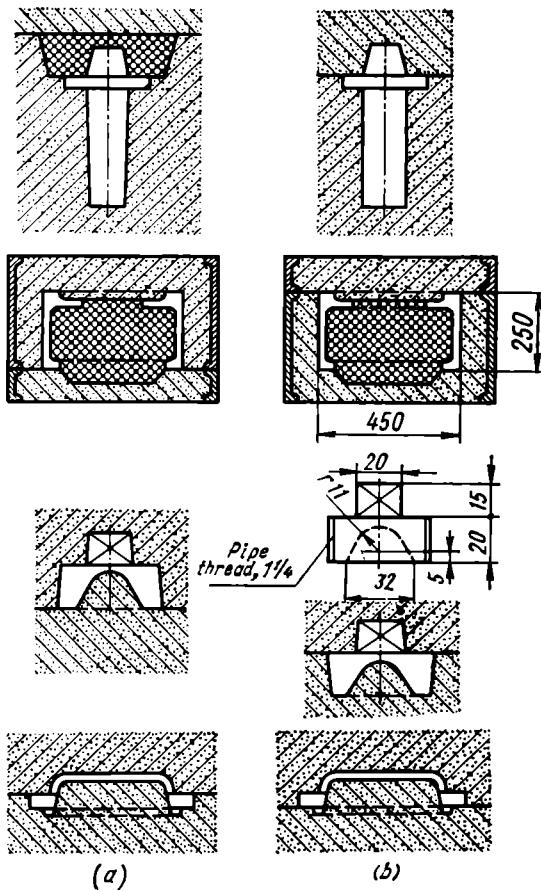


Fig. 128. Examples of a correct (a) and an incorrect (b) choice of mold joints

small and medium-sized cores not more than once; place the ready core on the drying plate in the same position as it occupies prior to being set in the mold, thereby providing for its easier dressing and transportation; and exclude the turnover operation for a large core whose handling requires a crane.

The chosen contours of the core should allow for easy setting of the core in the mold and for checking of all its dimensions. In the core arrangement of Fig. 130, the molder first inserts the core C1 into the mold, and then cores C2 and C3. The last two

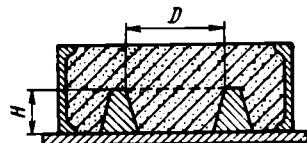


Fig. 129. Determining the size of projection cores

cores are made as separate elements because the single unit would not enter into the mold cavity. For the convenience of setting in the core C₂, the core print of core C₃ must be 15 mm longer than the recess *a* in the core C₁.

If the casting should have two cavities communicating with a channel, it is necessary to employ two cores because one core made for the purpose would tear off at the neck 1 (Fig. 131).

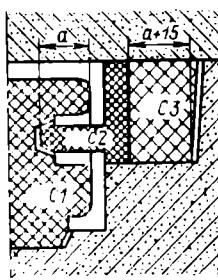


Fig. 130. Choosing core limits to provide for easy setting of cores in a mold during its assembly

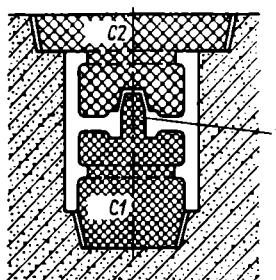


Fig. 131. Contours of cores for forming two cavities in the mold which communicate through a narrow channel

Breaking down a complex core into simple elements allows for using the machine method of production followed by cementing of the elements or assembling of the core. When setting up the limits of cores, the designer should take account of the shape of the casting and the overall dimensions which determine the amount of sand needed for the manufacture of the cores. The use of sands of increased

Table 28

Draft Allowances β and β_1 Versus the Height of Inside

Pattern	Vertical surface	Draft β and β_1 at surface		
		20	21-50	50-100
Metal	Outside	$1^{\circ}30'$	1°	$0^{\circ}45'$
	Inside	3°	2°	1°
Wood	Outside	3°	$1^{\circ}30'$	1°
	Inside	3°	2°	$1^{\circ}30'$

dry strength permits the production of hollow cores instead of solid ones. This also improves the gas permeability of cores, cuts down the core drying period and decreases the amount of sand spent on the cores. For castings whose inside surfaces should have a particularly smooth finish, it is desirable to use hollow, shell cores made from quartz- or zirconium-base sands bonded with powdered bakelite.

In choosing the method of molding, the designer should consider the possibilities for preparing the molds and cores on molding machines, since the machine method produces castings with minimum machining allowances and with good smoothness of the surface.

The choice of the overall dimensions of flasks depends on the size, the number and the location of patterns in the mold, and also on the dimensions of gating systems and core prints of cores.

The designer should also consider the mass of assembled half-molds, the lifting capacity of cranes, the size of molding tables on the machines and also the size of available flasks. Apart from the above factors, the designer should give due consideration to the following: (1) the thickness of the molding sand layer around the casting, which should be strong enough to withstand the pressure of molten metal poured into the mold (the distance from the casting or pattern to the walls of shallow, medium-sized, and large flasks is taken to be 30-50 mm, 50-100 mm and 100-150 mm respectively); (2) the distance from the core print to the flask wall (which should be from about 40 to 50 mm); and (3) the distance from the pattern to the bottom or top plane of the flask (this distance should range from 40 to 60 mm, 60 to 120 mm, and 100 to 150 mm for shallow, medium-sized, and large flasks respectively).

In molding a few patterns in a single flask, the distance between the patterns in the parting plane should be not less than 20 mm for thin-walled pieces cast in shallow molds and not less than 30 mm for thick-walled pieces cast in deep molds.

and Outside Pattern Surfaces

height h_{out} , mm				
101-200	201-300	301-600	601-2 000	2 000
0°30' 0°45'	0°30' 0°45'	0°20' 0°30'	0°20' 0°30'	— —
0°45' 1°	0°30' 1°	0°30' 0°45'	0°20' 0°30'	0°15' 0°30'

Working out the casting drawing. In mass and large-lot production, it is usual to work out a special drawing of the casting. In small-lot and piece production of castings, the designer marks on the part drawing the parting line of a pattern or mold, position of the casting during pouring, tapers, machining allowances, location of cores and size of core prints, loose pattern pieces, risers, flowoffs, gates, bosses, and chills.

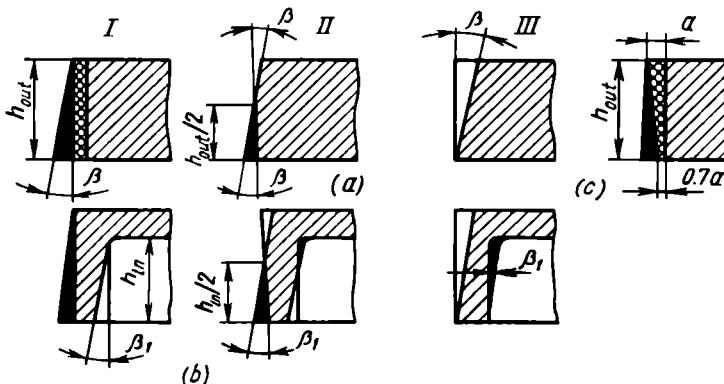


Fig. 132. Variants I, II, and III of applying pattern drafts to pattern surface
(a) external drafts; (b) internal drafts; (c) external drafts to walls less than 500 mm in height

The joint of a pattern or mold is shown as a solid line on all the projections of the part drawing and denoted by letters *P* and *M* respectively. The position of a casting during pouring is marked with arrows. The cope and drag halves of the mold are labelled *C* and *D* respectively, the letters being marked near the parting line. If a pattern is of the solid type, only the mold joint *M* is shown on the drawing.

Draft allowances. In the absence of design drafts on the part drawing, the technologist-founder marks the pattern (mold) drafts on the working drawing of the casting. The pattern maker then applies these drafts to the pattern, considering the data given in Table 28.

There are three methods of forming drafts on patterns (Fig. 132). By the first method (variant *I*), the pattern maker applies the taper over the stock *a* left for machining, for example, the taper β (Fig. 132a) which subsequently forms on vertical casting walls of height h_{out} . If the vertical wall of a casting is not to be machined and its thickness is less than 8 mm, the taper β_1 (Fig. 132b) is made by the same first method.

By the second method (variant *II*), the pattern maker forms drafts β by increasing or decreasing the thickness of vertical pattern

walls. These drafts are specified for casting walls 8 to 12 mm thick not subject to machining.

By the third method (variant III), the pattern maker decreases the pattern wall thickness to obtain the drafts β if the height of the piece to be cast is less than 100 mm and the wall thickness is over 12 mm. These drafts are specified for casting walls to be left as cast. If the height of an as-cast vertical wall is to be over 100 mm and the thickness over 12 mm, the draft allowance is made by increasing or decreasing the pattern wall thickness (according to variant II). Table 28 gives the list of minimum pattern drafts.

The stiffening ribs and other nonmating faces of patterns are given a larger amount of draft than the values listed in the table. If the height of the vertical wall subject to machining is smaller than 500 mm, the draft in the pattern is formed by the first method, but the allowance for machining the lower portion of the wall is decreased by 30% (Fig. 132c) because the molten metal poured into the mold deforms the mold walls and thus causes an increase in the thickness of casting walls. For high ribs and dividing walls 6 to 10 mm thick, the draft angle may range to about 3°.

Shrinkage allowances. In the conditions of piece and lot production, the technologist-founder indicates the percent shrinkage for the alloy to be cast on the casting drawing being worked out. The pattern maker allows for alloy shrinkage when he manufactures the pattern.

In mass and large-lot production, the technologist-founder makes due allowance for the alloy shrinkage when he determines the dimensions of pattern and core boxes and elaborates the casting drawing and the drawings of the patterns and core boxes. The linear shrinkage in percent is found from the formula

$$\epsilon_l = \frac{l_p - l_c}{l_c} 100$$

where l_p and l_c are the drawing dimensions of the pattern and casting respectively.

The linear percentage shrinkages for some casting metals and alloys are as follows:

Iron:

gray	0.6-1.3
white	1.6-2.3
malleable, pearlitic . . .	1.2-2.0
malleable, ferritic . . .	1.0-1.2
austenitic	1.3-2.0
iron-aluminium alloy (18-25% Al)	2.4-2.7

Steel:

carbon (0.14-0.75% C) . .	1.5-2.0
manganese (10-14% Mn) . .	2.5-3.8
heat-resistant	1.8-2.2

Bronze:

tin	1.4-1.6
aluminium . . .	1.5-2.4

Brass:

yellow	1.5-2.2
silicon	1.6-1.8

Alloys:

silumin (5-14% Si)	1.0-1.2
aluminum	1.0-2.0
magnesium	1.1-1.9
zinc	1.0-1.5

However, the shrinkages for the castings proper differ from the shrinkages for the alloys. The castings of simple shape show the highest shrinkage because they present no obstacles to metal contraction. The castings with walls varying in thickness shrink unevenly because of the nonuniform cooling and solidification of the entire casting (massive walls solidify longer than thin ones). The castings with a large number of cores also shrink nonuniformly because the cores impede metal contraction.

The actual shrinkage of a casting, which takes into account the nonuniform cooling and the resistance the mold and cores offer to the metal as it contracts, is called the *casting shrinkage*, or contraction. The shrinkage of a casting, commonly derived from experiment, is allowed for when correcting the working dimensions of the pattern.

The stock left for machining is marked on the part drawing with thin solid lines and hatched only in sectional views. The figures indicating machining allowances are written above the surface roughness symbols. These machine-finish allowances depend on the kind of metal cast (Tables 29-31). The upper portion of a casting must be given a larger oversize than the lower and side portions because, as noted earlier, slag accumulates most heavily in this portion and blows appear on its surface. In the mass, lot, and piece production of gray-iron castings, it is possible to obtain core holes measuring respectively over 20, 30, and 50 mm in diameter.

The negative allowance indicates the amount by which a pattern must be made undersize (as against the size given in the part drawing) to compensate for a possible error occurring in the production of the mold and cores. This dimensional inaccuracy usually appears in hand molding when rapping the pattern to remove it from the mold, finishing up the mold and cores, and as a result of other influences. The negative allowance is made by decreasing the external dimensions of a pattern.

The positioning of cores in the mold is determined at the blueprint stage from the part drawing. The designer then marks out the preliminary boundaries between the main cores; determines the number of cores required, the purpose each core must serve, the conditions and methods of core production; chooses the right types of core grids and vents, the composition of sand, the conditions of drying; defines the contours and size of core prints and also the clearances over the core print contours for each core.

The core print dimensions and the clearances between the core prints of cores and core print seats (core prints of the mold) are taken from Tables 32, 33, 34.

Table 29

Machining Allowances for Gray-Iron Castings of Accuracy Classes I, II, III, mm

Maximum overall dimension of the casting, mm	Position of surface in pouring	Nominal dimension*, mm							
		≤ 50		50-120			120-260		
		I	II	I	II	III	I	II	III
≤ 120	Top	2.5	3.5	2.5	4.0	4.5	—	—	—
	Bottom, side	2.0	2.5	2.0	3.0	3.5			
121-200	Top	2.5	4.0	3.0	4.5	5.0	3.0	5.0	5.5
	Bottom, side	2.0	3.0	2.5	3.5	4.0	2.5	4.0	4.5
261-500	Top	3.5	4.5	3.5	5.0	6.0	4.0	6.0	7.0
	Bottom, side	2.5	3.5	3.0	4.0	4.5	3.5	4.5	5.0
501-800	Top	4.5	5.0	4.5	6.0	7.0	5.0	6.5	7.0
	Bottom, side	3.5	4.0	3.5	4.5	5.0	4.0	4.5	5.0
801-1250	Top	5.0	6.0	5.0	7.0	7.0	6.0	7.0	8.0
	Bottom, side	3.5	4.0	4.0	5.0	5.5	4.5	5.0	6.0
1251-2000	Top	5.5	7.0	6.0	7.5	8.0	6.5	8.0	8.0
	Bottom, side	4.0	4.5	4.5	5.0	6.0	4.5	5.5	6.0
2001-3150	Top	6.0	7.0	6.5	7.5	9.0	6.5	8.0	9.0
	Bottom, side	4.0	5.0	4.5	5.0	7.0	4.5	5.0	7.0
3151-5000	Top	6.0	7.5	6.5	7.5	9.0	7.0	8.0	10.0
	Bottom, side	4.5	5.5	5.0	5.5	7.0	5.0	6.0	8.0
5001-6300	Top	—	7.5	—	8.0	9.0	—	8.5	10.0
	Bottom, side	—	5.5	—	6.0	7.0	—	6.5	8.0
6301-10000	Top	—	—	—	—	9.0	—	—	10.0
	Bottom, side	—	—	—	—	7.0	—	—	8.0

* The nominal dimension is the maximum distance between the opposite faces to be machined, or the distance from the reference surface or axis (of the casting, part) to the surface to be machined.

Table 30
Machining Allowances for Steel Castings of Accuracy Classes I, II, III, mm

Table 31
Machining Allowances for Castings from Nonferrous Alloys*, mm

Maximum overall dimension, mm	Production					
	mass		batch		piece	
	casting shape					
	simple	complex	simple	complex	simple	complex
200	2	2	2	3	3	4
201-300	2	2	2	4	4	5
301-500	3	3	3	5	5	6
501-800	3	4	4	5	5	7
801-1 200	4	5	5	6	6	8
1 201-1 800	4	5	5	7	7	9

* Bronze, brass, and silumin.

Table 32
Height h_l of Lower Vertical Core Prints and Length l of Horizontal Core Prints* of Green Sand Cores, mm

Diameter D or $A + B$, $\frac{2}{mm}$	Core length L , mm									
	≤ 50		51-150		151-300		301-500		501-750	
	h_l	l	h_l	l	h_l	l	h_l	l	h_l	l
To 25	20	15	25	25	—	40	—	—	—	—
26-50	20	20	40	35	60	45	70	60	—	—
51-100	25	25	35	40	50	50	70	70	100	90
101-200	30	30	30	50	40	55	60	80	90	100
201-300	35	—	35	—	40	60	50	90	80	110
301-400	40	—	40	—	40	80	50	100	70	120
401-500	40	—	40	—	40	100	50	120	60	130

* For double-seat horizontal cores.

Core contours are marked on the drawing with thin solid lines. Cores are crosshatched in section only partially, near the contour lines. The clearances between the core prints and core print seats are shown on the part drawing only when they depart from the values given in the specifications. The mating portions of cores are traced on the part drawing with a bold or double thin line. The number of a core corresponds to the number that designates the place the core occupies in the ordered sequence of arrangement of cores in the mold.

Table 33
Draft Angles for Core Prints (see Fig. 135)

Core print height h_l or h_{up} , mm	Core print					
	vertical		horizontal			
	α	β	α	α_1	β	
≤ 20	10°	15°	10°	3°	15°	
21-50	7°	10°	7°	1°30'	10°	
51-100	6°	8°	6°	1°	8°	
101-200	5°	6°	5°	0°45'	6°	

Table 34
Clearances between Core Prints of Green Sand Cores and Core Print Seats in Green Sand Molds, mm

Core print height h_l or h_{up} , mm	Clearance S_1 at core length L or core diameter D , mm								Clearance S_2
	< 50	51-100	101-300	301-500	501-750	751-1 000	1 001-1 500	1 501-2 000	
< 25	0.15	0.15	0.25	—	—	—	—	—	—
26-50	0.25	0.15	0.5	1.0	1.0	1.5	—	—	1.5-2.5
51-100	0.5	0.5	1.0	1.0	1.5	2.0	2.5	3.0	2.0-5.0
101-200	1.0	1.0	1.0	1.5	2.0	2.5	3.0	3.5	3.0-6.0
201-300	1.0	1.0	1.0	1.5	2.0	2.5	3.0	3.5	3.0-6.0
301-500	1.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.0-7.5
Clearance S_2	0.45	0.25	0.5	1.0	1.5	2.0	3.0	3.0	—

In the drawing, a core number, for example, *C5*, is written in the core center.

Cores made in the same core box both with and without loose sides are designated by identical consecutive numbers, though the numbers of the latter cores have indexes added to differentiate between the two types (for example 1, 1a, 2, 2a). The plane of core ramming is indicated with an arrow, and the parting plane with an arrow of the type 4-4.

The dimensional accuracy of a casting is largely determined by the accuracy of location (fixing) of cores in the mold during the mold assembly. The accuracy of location of a core depends on the shape of

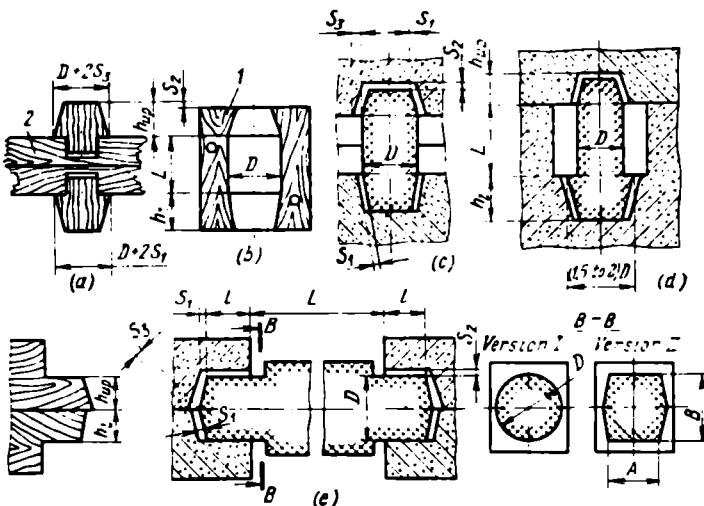


Fig. 133. Dimensions of vertical and horizontal core prints of cores
 (a) core prints of pattern; (b) core box; (c) and (d) clearances in the mold for vertical cores;
 (e) clearances in the mold for horizontal cores

its core prints (registers) and on core print dimensions which are selected from Tables 32, 33 and 34, taking into consideration the size of the core, method of core molding, and its position in the mold (Figs. 133, 134).

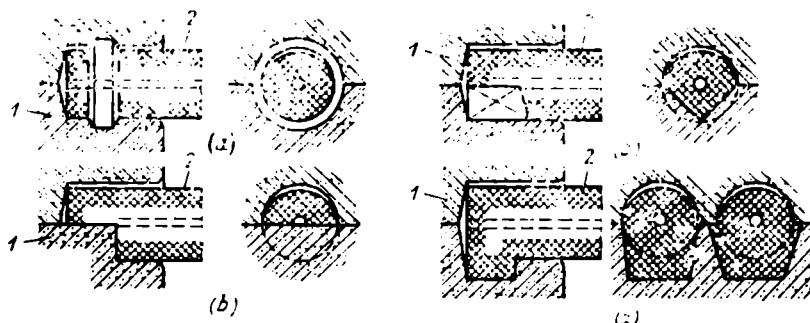


Fig. 134. Core prints with registers which preclude
 (a) axial displacement; (b) and (c) turning; (d) axial displacement and turning; 1—mold;
 2—core

The height h_1 of lower core prints (see Table 32) is taken with due regard for the core length L and core diameter D , or quantity $(A + B)/2$ for cores of rectangular cross section (see Fig. 133).

The height h_{up} of upper core prints of vertical cores is determined from the height h_l that stands in the respective row:

h_l , mm	20	25	30	35	40	50	60	70	80	90	100
h_{up} , mm	15	15	20	20	25	30	35	40	50	55	60
h_l , mm	110	120	130	140	150	160	170	180	190	200	
h_{up} , mm	65	70	80	85	90	95	100	110	115	120	

The length l of horizontal core prints (Fig. 133e) depends on the method of core molding. The values of l for green sand cores are listed in Table 32; for dry sand cores, these values should be decreased a little. The length of core prints of floating cores can be increased to the core length L .

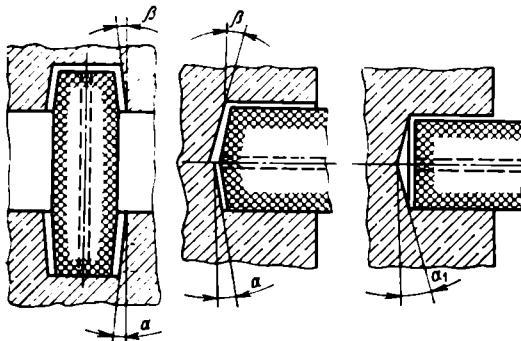


Fig. 135. Taper of the core prints of cores

The core prints of cores are tapered as shown in Fig. 135 to facilitate assembling of the mold and improve its dimensional accuracy. The draft angles for core prints are listed in Table 33.

The clearances between the surfaces of core print seats (impressions in the mold) and core prints of cores are marked on the production drawing. These clearances enable the correct location of cores in the mold. If the clearances are too small or there are no clearances at all, it is impossible to assemble the mold without damaging it or disturbing its preset dimensions.

Too large clearances change the size of castings since they become responsible for the formation of projecting ridges (flashes) of metal at the junctions of cores and mold walls. Besides, such clearances let molten metal penetrate into core vents, which may lead to the formation of blowholes in castings.

The core prints of cores must enter into the respective imprints in the mold as easily and precisely as possible. For this the diameter and base width of the core prints of a pattern 2 (Fig. 133a) are made larger than the respective dimensions of a core box 1 (Fig. 133b) by a double value of clearance S_1 (for the lower core print) or of clearance S_2 (for the upper core print). The height h_{up} of the upper

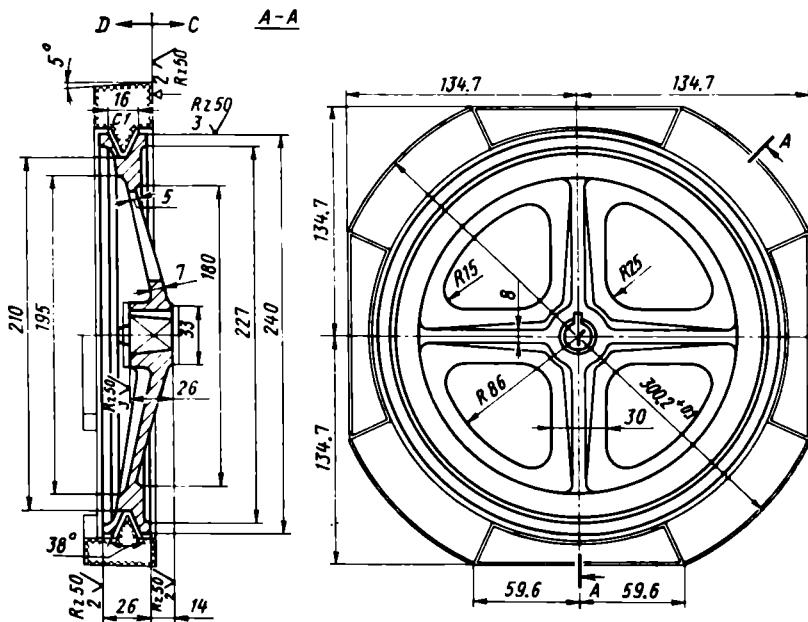


Fig. 136. An example of working out the production drawing of a compressor pulley casting

core print of the pattern exceeds the height of the core print of the core by the value of S_2 (Fig. 133c). If the ratio between the core length L and core diameter D is equal to or greater than 5, it is advisable to increase the diameter of the lower core print base 1.5-2 times over the core diameter (Fig. 133d). The tentative clearances are given in Table 34.

The gating system, flowoffs and risers, cast-on test bars, pattern reinforcing ribs, and chills are drawn with thin solid lines, the dimensions being indicated where necessary.

Forms and records on the production of castings (process documentation). The process chart is the basic document which records the steps of the production process, the operating conditions, the technique and sequence of performing all the operations involved in the manufacture of the casting. The operation sheet gives the name of the part to be cast, specifies the type of molding machine, indicates the number of parts per item, the pouring and the net mass of the casting, the method of molding (in green sand, in dry sand, with or without cores), the number of castings and cores in the mold, and so on.

Besides, the operation sheet outlines in brief the basic process operations (molding, mold assembly, coremaking and core drying,

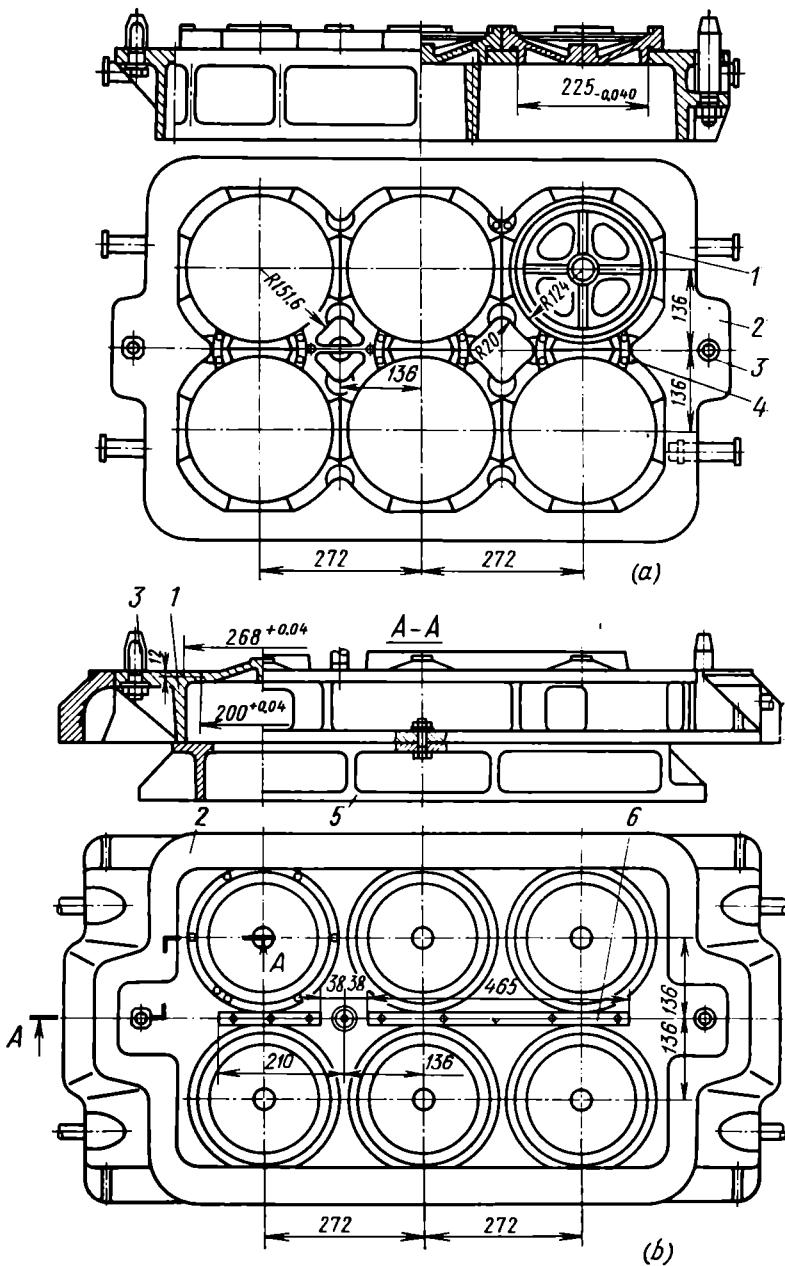


Fig. 137. Pattern plates used in the manufacture of a pulley casting
 (a) lower pattern plate; (b) upper pattern plate; 1—pattern; 2—plate; 3—centering pin;
 4—gating pattern; 5—machine plate; 6—runner pattern

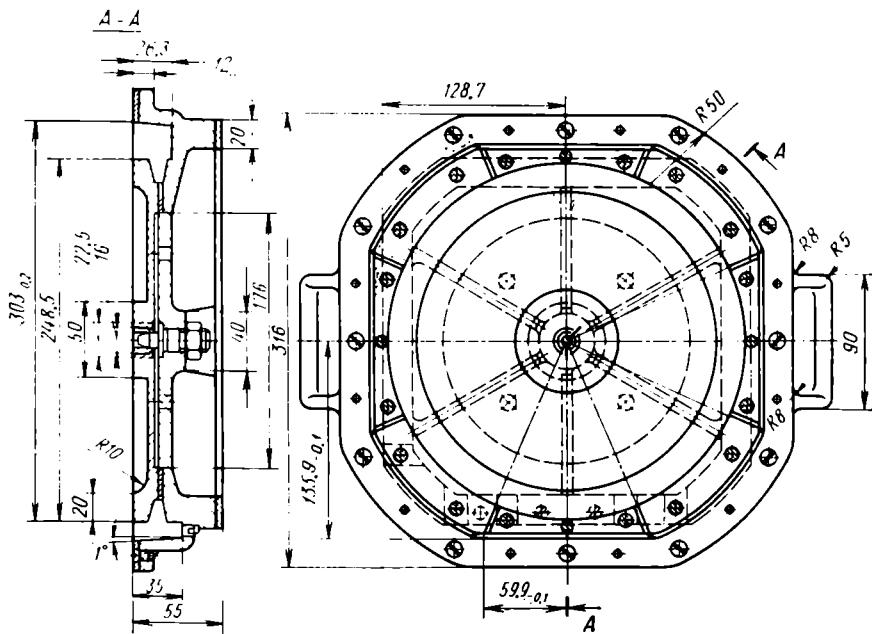


Fig. 138. Core box for making the core used to form the groove in the rim of a pulley casting

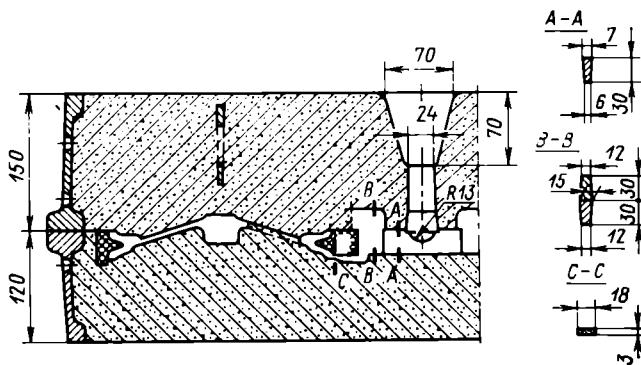


Fig. 139. Mold for a pulley casting

metal pouring, casting shakeout, flogging or chipping to remove gates and risers from the casting, core knockout, cleaning of the casting, and other operations).

The charts and forms also specify the necessary equipment, the main and auxiliary tools, indicate the machine output per shift, the skill category and the number of workers required, the rate of wages per hour and per casting.

The process documentation also includes the drawings of the casting, patterns, and the assembled mold.

Figure 136 illustrates the production drawing of a compressor pulley casting, which gives the machining allowances, pattern drafts, and shows the parting line between the cope and drag. Fig. 137 shows pattern plates to which are fastened the patterns of the pulley and the gating patterns. The core that forms the groove in the pulley rim is made in a metal core box (Fig. 138) consisting of two parts centered with a pin. The sectional view of the assembled mold with the elements of the gating system is given in Fig. 139.

Chapter 9. COST EFFECTIVENESS OF METAL CASTING

9.1. TECHNICAL-AND-ECONOMIC INDEXES

Foundries supply cast workpieces practically for all the branches of machine and instrument engineering. In this connection, foundrymen must seek to increase the economic efficiency of production and improve the quality of castings. To attain the objective at a minimum of expenses, the foundry must search for the ways of saving on the costs of materials, fuels, and electric power, adopt the most efficient manufacturing methods developed on the basis of the latest achievements in science and technology, and thus reduce the cost of products.

The cost of a product is the sum total of expenses incurred in its manufacture and marketing. Any change in the production process has an effect on the product cost. Thus, it is possible to decrease the cost of products by increasing labor productivity, cutting down the expenditures on materials, fuels, electric power, introducing progressive methods of production and efficient mechanized and automated processes.

The basic technical-and-economic indexes which characterize the production efficiency of a foundry shop include the output of sound castings, tons per year; labor input for the manufacture of one ton of sound castings per square meter of the total floor area of the foundry shop, tons; output of sound castings per production worker in the shop, tons per year; the shop cost of one ton of sound castings, rubles per ton.

The shop cost results from the sum of expenses for direct materials (such as molding sands, clay, binders, additives, and charge materials), process fuel, wages of direct labor (molders, coremakers, founders, pourers, fettlers, and others), overhead charges (on compressed air, water, repair of machinery and auxiliaries, accessory materials, wages of indirect labor, and so on).

The cost of castings largely depends on the accepted variant of the production process. That is why one of the important tasks set for the technologist-founder is to choose the right production process which could be economically optimal for the given operating conditions.

In general, to achieve high technical-and-economic indexes, the foundry must make every effort to increase the productivity of labor, step up the output and improve the quality of products, efficiently use fixed capital (such as machinery and working areas)

and current capital (stores of materials and fuels), reduce the cost of ready products, raise the qualification level of workers, technicians, and engineers, and also improve the working conditions.

9.2. ECONOMIC EFFICIENCY OF A CASTING PROCESS

The efficiency of a casting process depends on a large number of factors such as the shape of a casting, its mass and size, composition of the alloy, nature of production (piece, batch, or mass production), and method of preparing molds and cores.

One of the most important factors which affects the technical-and-economic indexes is the *technological effectiveness*, or feasibility, of the design of a casting, that is, the degree of its compliance with the optimal shop conditions of production for the accepted program of output. The technological effectiveness of the design of a casting is a complex notion; it is possible to judge this notion by the manufacturability indexes, which can be conditionally divided into two groups; the first group includes labor, material and cost indexes, and the second unification indexes. Labor, material, and cost indexes define the labor input, quantity of metal per casting, and the cost of castings. The lower the labor input, quantity of metal per casting, the cost of the casting at the stage of its manufacture in the foundry shop, and also the volume of work, finishing allowances, and the cost of machining in the machine shop, the more technologically feasible the casting design.

Unification indexes define the possibilities for standardizing the individual members of a casting (such as flat protrusions, bosses, holes of certain diameters, and wall thicknesses) in order to employ standard production techniques, auxiliaries, and tools for its manufacture and subsequent machining, and thus to cut down its cost and increase technical-and-economic indexes.

The general principles of evolving the design of a producible casting, depending on the manufacturing method and alloy composition, have been considered earlier. The technological effectiveness of the design of a casting (and the approaches the designer has come to in working out the casting design) must be assessed by technologists-founders and engineers engaged in thermal treatment and machining of castings. Only after the proper scrutiny can they choose the variant of the casting design which ensures high service characteristics of the casting and minimum time and labor required for its manufacture, thermal treatment, and machining.

It happens rather often that in the conditions of a given foundry the manufacture of a casting to the specified program of output proves economically unreasonable. Where this is the case, a cast-and-welded or forged construction may be a good alternative to the cast

part. Should it be necessary to make expressly the cast type, the customer gives an order to a specialized foundry.

Of much importance is the right choice of the material for a casting. Iron features good technological properties, so that iron castings are rather cheap. The casting yield comes to 50-60% for intricately shaped iron castings, and to 75-80% for simple iron castings. Steel castings are more expensive because steel melting requires a high consumption of energy and the casting process necessitates a larger amount of fresh molding materials and a greater quantity of metal for gates and risers. The casting yield amounts to 35-70%.

Aluminum and magnesium alloys are expensive. They are used where the need arises to have a casting of low mass, definite thermal conductivity and corrosion resistance. Copper alloys are expensive, but excel in useful properties; they have high thermal and electric conductivity, increased corrosion stability, and a low coefficient of friction. Copper alloys are valued for special constructions of machines.

If we assume the cost of one ton of iron castings to be unity, then the relative cost of castings from various alloys will be such:

Iron: gray	1.0
high-strength	1.1-1.3
malleable	1.2-1.5
Steel: carbon	1.5-2.0
high-carbon	6.0-8.0
Copper alloys	6.0-8.0
Aluminium and magnesium alloys	8.0-10.0

The cost of castings also depends on the manufacturing method employed. Many special casting techniques secure high dimensional accuracy of castings, small machining allowances, and good labor productivity through automation of labor-consuming operations. However, the final decision on the use of a most expedient method can be made only after a scrutiny of the cost effectiveness, giving due consideration for the range of pieces to be cast and for the conditions of production.

With an increased length of run (batch size), the labor input and the cost of castings decrease, and vice versa.

As the batch size diminishes, the specific expenses for the production of molding equipment (patterns, core boxes, pressure casting dies, metal molds) grow. In short-run production, it is expedient to use the cheapest possible molding equipment whose manufacture calls for a minimum of labor and materials. That is why many casting techniques (such as die casting and shell casting) which necessitate costly molding equipment are impractical in piece or short-run production. Foundrymen are persistent at improving, simplifying, and making cheaper the molding equipment. For example, the full mold process lends itself to the manufacture of large indi-

vidual castings. The labor input required for the production of individual expendable patterns is only one half to one fifth of that for wood patterns. This, in turn, helps decrease drastically the time and labor needed for the manufacture of castings and thus sharply reduce the production costs.

When planning particularly long runs, it is economically advantageous to employ more elaborate, though costly, molding equipment and automate production processes and handling operations on a large scale. The outcome will be a sharp decrease in the cost of castings. Thus, in employing the casting techniques which require costly molding equipment, the labor input decreases very significantly indeed with an increase in the length of runs. An example given below shows how the labor input (man-hours per piece cast) vary with the batch size of castings produced by the investment casting process.

Yearly output, pieces	Man-hours per piece
25	2 000-3 000
50	1 200-1 800
150	800-500
500	400-500

Putting into service an ever increasing number of specialized foundry shops adapted to turn out a certain range of castings can ensure high technical-and-economic indexes and improved quality of castings.

In estimating the efficiency of a casting process, proper consideration must be given to the cost of materials used for molds and cores. For example, the shell casting process can produce castings from iron, steel, and copper alloys of increased dimensional accuracy and low surface roughness. The savings here result from a decreased pouring mass of castings, smaller machining allowances, improved efficiency of production of molds and cores, and lower labor input in fettling and cleaning operations. The data below allows us to compare the labor input (in working hours) for the production of one ton of castings in green-sand molds and the labor input required to produce one ton of castings in shell molds.

Time required to produce one ton of castings, h

Operation	Mold	
	sand	shell
Preparation of sand	3	0.5
Molding	10	5
Shakeout	2	0.5
Cleaning of castings	10	5
Other operations	15	15
Total	40	26

The sands used for shell molds need a costly binder, known as powdered bakelite, therefore despite the fact that shell molds

require only one tenth the amount of sand spent on sand molds, in many cases it proves unprofitable to convert to shell casting to produce certain parts. Practical experience and economic analysis show that it is most expeditious to convert to shell casting for the production of shaped parts which require the use of cores and consume much labor and time in cleaning and fettling operations, or the parts commonly made from forgings or rolled iron. The right choice of both the range of parts for casting in shell molds and automatic equipment permits decreasing the total labor content by 30-50% and the cost of castings by 20-30% in comparison with casting in sand molds.

When evaluating the factors which govern the choice between the process of casting in metal molds (permanent-mold casting) and some other process, one should keep in mind that permanent-mold casting permits us to decrease machining allowances by 50-66%, increase the casting yield to 75-90%, effect considerable savings in, or, sometimes, completely eliminate the need for, molding and core sands, exclude labor-consuming molding and mold knockout operations, thereby allowing for full mechanization and automatization of the production process.

At the same time, one should not neglect the high cost and limited durability of metal molds. Thus, from the standpoint of economy, the production run for iron castings should be not less than 400 pieces a year, and for aluminum castings not less than 400-700 pieces a year. Hence, an important practical task the engineers must work at to expand the field of application of this progressive production process is to seek the ways of increasing the durability of metal molds and decreasing the time and labor required to produce each one.

The present level of technology and automation of the permanent-mold casting process permits decreasing the cost of cast products by 15-30% against the cost of sand mold castings.

When deciding on whether it is practical to convert to die casting, both technical and economic pros and cons must be properly considered.

Because of a high cost of molding dies, die casting makes an efficient process only in the mass and large-lot production of castings from light alloys (aluminum and magnesium), zinc and copper alloys. Complete automatization of the production process, from pouring into molds to fettling and trimming of castings, offers wide scope for more extensive application of this progressive technique of casting.

9.3. WAYS OF INCREASING ECONOMIC EFFICIENCY OF METAL CASTING

The technical progress involves the development of efficient methods of production of new materials and machines, improved processes of treatment of materials, and advanced forms of organization of work which ensure high efficiency of labor. The basic trends of modern engineering which make possible the technical progress are as follows.

Wide use of electric power in industry for carrying out production processes, driving tools, controlling and monitoring various operations. In foundry practice, for example, the extensive use of electric furnaces (induction and arc ones) makes it possible to improve the quality of molten metal and, hence, the quality of castings, decrease the consumption of energy per heat, improve the working conditions, and increase production efficiency.

All-round mechanization and automatization of production processes, that is, replacement of hand labor by increasingly intricate systems of automatic machines, robots, manipulators, electronic computers which perform main and auxiliary production operations and exercise control and monitoring. This trend is particularly important to the foundry because casting processes involve a large number of labor-consuming operations. Automatic foundry machinery is gradually supplanting hand labor. Automatic machines now in use at many foundries form molds, prepare molding and core sands, make cores, pour metal into molds, and handle shakeout and cleaning operations.

Introduction of chemical methods of material processing into process engineering and application of new synthetic materials. Foundries make wide use of new binders which set when in contact with the hot pattern rig, and also cold-setting binders. Casting in shell molds produced from liquid self-curing mixes and cold-hardening sands, investment casting, and the full mold process may serve as examples of how modern foundry practice draws on the gains achieved in chemistry.

Thus, the technical progress in foundry practice rests on the achievements in natural and technical sciences, since the knowledge so obtained helps solve production problems.

Part II

BASIC THEORY

OF CASTING

Chapter 1. INTERACTION OF THE MOLD WITH MOLTEN METAL

1.1. GASES IN CASTINGS

Castings are often subject to gas porosity, both closed and open (see Fig. 179). Gas cavities (blowholes, for example) are voids in the casting material, the surface of which is clean, smooth, and nonoxidized, or shows small colored oxide spots (flowers). Blowholes and blows (surface defects) like any other discontinuities in a casting, decrease its strength and therefore are inadmissible. Castings with gas cavities are usually rejected.

Gases in the metal of a casting can be present as compounds and solutions. The gases dissolved in metal impair its plasticity, tend to form blowholes and pinholes in the casting as they leave the solution. Gas porosity affects the quality of castings, but this surface defect is remediable. Gases present in molten metal as compounds can cause fissures, intercrystalline cracks, and other defects.

Solubility of gases in liquid metals and alloys. Metals and alloys both in liquid and in solid states dissolve a considerable amount of gases. A melt can absorb gases from the moist, rusty, or oil-coated scrap charged into the melting furnace, from the air supplied to the furnace for fuel burning, from the moisture contained in fuel, ore, and fluxes, and also as a result of prolonged contact of the melt with the furnace atmosphere whose gases can dissolve in the molten metal.

The solubility of a gas in melts obeys the equation

$$s = K \sqrt{p_1 - p_2}$$

where s is the amount of gas dissolved in an alloy, $\text{cm}^3/100 \text{ g}$, K is the solubility constant dependent on temperature, p_1 and p_2 are partial pressures of the gas in the surrounding atmosphere and in the melt respectively.

The solubility of a gas in a liquid alloy grows with the partial pressure of the gas above the melt surface. As the temperature rises, the solubility of a gas that does not form chemical compounds with metal rises too. A gas that forms chemical compounds with metal

is less soluble at high temperature than at lower temperatures. Hydrogen, nitrogen, and oxygen show the highest solubility in ferrous alloys. Hydrogen in solution appears to be in the ionic state; the volume of hydrogen dissolved in 100 g of pure iron at 1 550°C is equal to 27.8 cm³. The hydrogen content of steel, however, does not exceed 10-20 cm³/100 g. Hydrogen present in steel and in non-ferrous metals is responsible for the formation of pores, floccules, and cracks.

Hydrogen in liquid alloys exists as oxides such as FeO, MnO, and Al₂O₃. The form in which nitrogen exists in liquid alloys has not yet been clearly ascertained. Some researchers suggest that in iron-carbon alloys nitrogen is present as nitrides of iron, silicon, titanium, and other elements.

The solubility of gases sharply decreases with lowered temperature, so that alloys are apt to give off gases as they undergo crystallization. Hydrogen is considered to be most prone to form an independent phase (bubbles).

Carbon monoxide is insignificantly soluble in metals, therefore there is reason to believe that carbon monoxide present in liquid steel results from chemical reactions. Polyatomic gases are not directly soluble in metals, but they are able to dissociate and evolve, for example, hydrogen which dissolves in metals.

Reactions that produce gases. One of these is the reaction of reduction of ferrous oxide, FeO, by carbon in rising steel:



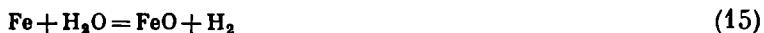
If this reaction is not completed before pouring the metal into a mold, it proceeds in the mold. Since the bubbles of CO fail to escape from the metal because of its high rate of cooling, blowholes appear in the resultant casting.

In casting insufficiently deoxidized copper alloys, copper oxide may undergo reduction to copper by carbon which enters the composition of mold coatings:



This reaction proceeds most vigorously in the zone of high temperatures, namely, near the runner, and often causes the formation of gas cavities in castings.

Moisture contained in the molding sand evaporates under the heat of molten metal and can interact with iron-carbon alloys:



The evolved hydrogen dissolves in metal, while ferrous oxide, FeO, interacts with carbon in the alloy according to reaction (13)

and favors the formation of CO and, hence, causes gas porosity in castings.

Entrapment of gases in metal. This happens during pouring by way of injection of the air and gases and also intrusion of the gases into the casting from the surface of the gaseous stream. Air injection takes place as the melt flows through the gating system. The incoming metal can entrain the air in the sprue basin or cup, too, for which reason the design of the cup must secure separation of not only slag particles from the metal but also of air bubbles. The level of metal in the cup should be kept as high as possible to prevent initiation of a vortex flow (see Fig. 83) which sucks the air into the sprue. The air and gases can also penetrate into the casting through gas-permeable gate walls at the places where the metal enters the cavity at a high rate or flows over sharp protrusions, thereby causing rarefaction (Fig. 140).

If the bubbles of air and gases trapped in the metal escape the runner or other gates, they get into the casting and cause blowholes and porosity. Obviously, the gating system must be filled in completely with metal, and the pressure in all its portions must be above the pressure of gases in gate walls.

Penetration of gases into the casting through the metal-sand interface. During pouring of metal into the mold, gas-generating substances disintegrate and evolve vapors and gases. An increased volume of gases in the molding material tends to raise the gas pressure in sand pores. The excess pressure expels the evolved gases from the pores into the atmosphere. So, the mold filled with molten metal works under certain gas conditions, along with thermal conditions. The gas pressure in pores of the mold and cores depends on the rate of liberation and removal of gases, and also on the volume of pores serving in the given case as reservoirs and channels through which gases move in either direction. In turn, the processes of gas generation and removal depend on the gas evolution capacity and gas permeability of molding sands.

Gas conditions in a mold heavily affect the quality of the casting. Unfavourable gas conditions may be responsible for such defects as veining, rat tails, scabs, burning-on and metal penetration, blisters, and blowholes.

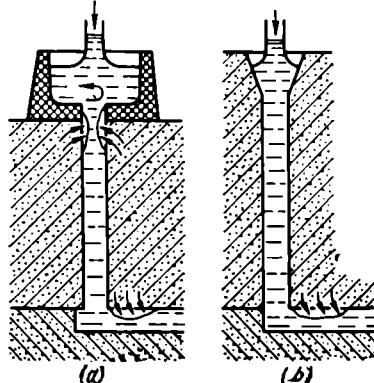


Fig. 140. Rarefaction in a mold and gas injection on pouring through a sprue cup (a) and from a bottom-tap ladle (b)

Penetration of gases from the mold into metal. Common sources of gases being evolved from the mold at the moment of metal pouring and during further cooling of the casting include:

1. The air which fills mold pores and expands under heat.
2. Moisture in the molding sand, which evaporates rather vigorously in filling green-sand molds.
3. Organic substances accidentally got into the sand or intentionally introduced as additives (coal, binders).
4. The air expelled from the mold by the metal stream during pouring.
5. Chemical reactions at the surface of contact between the metal and molding sand.

The vapors and gases liberated from the mold build up high pressure at the sand-metal interface.

If the resistance the molding sand offers to the motion of gases from the sand-metal interface into the mold is higher than the resistance to the flow of gases into the molten metal, then the mold will operate under the conditions which may foster gas porosity in the casting.

Gases cease to penetrate into the casting body from the mold once a sufficiently hard skin of metal forms on the casting. Such a skin forms fast on castings from pure metals and eutectic alloys showing a narrow range of crystallization (solidification range). The blowholes in these castings most often result from gas bubbles which appear right at the beginning of pouring. In casting of alloys which show a wide crystallization range and solidify in a large two-phase (solid-liquid) zone, the gas bubbles, while floating up, experience an added resistance of growing crystals. Besides, a uniform skin on castings made from these alloys forms more slowly. So, when casting the alloys having a wide solidification range, there is more risk of developing gas cavities due to the resistance of growing crystals.

Degassing metals and alloys. It is possible to eliminate to a certain extent such defects in castings as blowholes and pinholes if foundrymen strictly follow the adopted technological schedule at all the stages of production of a casting, from preparation of the molten metal to its pouring into the mold and solidification. There is a variety of measures taken to avoid the formation of gas cavities in castings, which can be divided into three groups.

The first group includes the precautions against saturation of an alloy with gases during its melting. Thus, one of the precautions involves careful cleaning of the charging material from rust, oil, and moisture before melting.

To prevent an alloy from absorbing gases during its melting in the furnace, the surface of melt is covered with a coat of liquid flux. An equally effective method is to carry on melting in a protective atmosphere that is inert to the molten metal. In melting the alloys

intended for particularly important castings, the charge should be preheated or calcined, or, sometimes, vacuum-treated.

Metals and alloys, such as titanium and its alloys, molybdenum, and others, used for castings where the gas content must be at a minimum, are commonly melted and poured in vacuum melting-and-pouring units.

The second group covers the measures called upon to exercise degassification of a molten alloy outside the melting unit before pouring into molds or during pouring.

The methods used for the purpose include vacuum treatment of the alloy in the ladle, pouring in vacuum units, ultrasound treatment, bubbling of inert gases such as chlorine, nitrogen, or argon through the molten alloy. The last method of degassing treatment, called the gas method, finds use in melting aluminum alloys.

Chlorine interacts with aluminum, forming a gas aluminum chloride, AlCl_3 . Hydrogen dissolved in the alloy diffuses into the bubbles of aluminum chloride that permeates the molten alloy. The hydrogen-containing bubbles float up to the melt surface and this flush hydrogen from the molten alloy.

Foundries make wide use of a presolidification method for degassing aluminum alloys. By this method, the alloy is allowed to cool and solidify very slowly in the crucible, thereby enabling the dissolved gases to escape into the atmosphere. The alloy is then heated to a predetermined temperature and poured into molds. The number of blowholes and the degree of porosity in aluminum castings are also possible to decrease not only by evacuating gases from the molten metal, but also by retarding this process, for instance, through crystallization of the metal at a pressure of 392-490 kPa (4-5 kgf cm⁻²) in autoclaves, using the method developed by the academician A. A. Bochvar and professor A. G. Spassky (see Part VI, Ch. 3).

The third group includes the measures taken to improve the quality of a mold. Of much concern here is to secure a directional flow of gas from the casting to the mold to enable the gas to escape into the atmosphere through the mold walls and core prints of cores. A simplified scheme of gaseous streams in the mold is illustrated in Fig. 141.

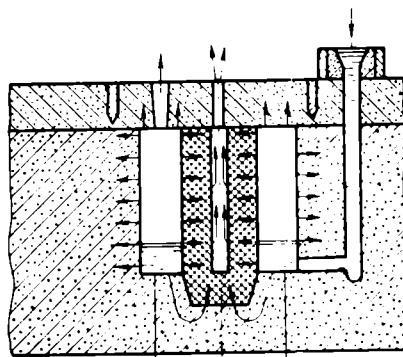


Fig. 141. Distribution of gas streams in a mold

To guard against the formation of blowholes in casting, it is necessary to take the following measures: (1) increase the gas permeability of molding and core sands and also molds and cores; (2) lower the moisture content of molding sands; (3) skin-dry molds; (4) coat the surface of molds with materials that raise its wettability, in particular, with graphite powders; and (5) use molding and core sands of the lowest gas evolution capacity possible.

1.2. EFFECT OF MOLTEN METAL ON THE MOLD

During pouring, solidification and cooling, metal gives up heat to the mold through convection, radiation, and by way of heat conduction. The longer the molten metal flows through a definite portion of the mold, the stronger the mold surface heats up and the



Fig. 142. Sand-metal mixture on the casting face

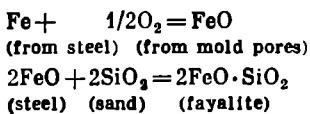
slower the metal cools down. Where the mold surface comes into contact with molten metal, intensive thermal, physicochemical, and mechanical processes are coming into play, which proceed in the course of pouring, solidification, and cooling of the metal. The processes bring about the formation of a strongly adhered layer of metal, its oxides, and sand grains (Fig. 142) on the casting surface. This phenomenon is often spoken of as burning-on and/or metal penetration. Burnt-on sand impairs the surface of a casting, complicates cleaning operations, and sharply diminishes the durability of tools used for its machining.

Burning-on may be classified under two types, *chemical* and *mechanical*. This conditional differentiation enables us to explain and show more vividly the causes of this phenomenon and preclude

its development during the production of castings. In reality, burning-on or metal penetration is an integral process.

Chemical burning-on occurs at the time of cooling and shrinkage of metal, that is, when the molding sand comes into contact with the semisolid or solid metal, whose temperature is still high. This type of burning-on is largely inherent in iron and steel castings because here the pouring temperature favors the formation of liquid silicates and, besides, the components of iron and steel have a chemical affinity for the mold's surface layer. Also, the high temperature on the surface of contact between the metal and sand holds on for a rather long period of time.

In the process of growth of an adhering sand layer on the surface of steel castings the following reactions take place:



It is clear from these reactions that the surface of steel castings oxidizes and the resultant iron oxides interact with silica, SiO_2 , to form fayalite whose melting temperature is below that of silica and steel.

Fayalite is a fluid-flow compound that penetrates into the mold skin. On the surface of the casting a defect thus appears in the form of a strongly adhered layer consisting of fayalite which envelopes sand grains.

It is an established fact that the sintered layer adheres to the casting only under definite conditions and it is quite possible to obtain castings with the burnt-on sand that can peel off readily enough.

What aids in the formation of the fused layer is the presence in molding sands of oxides of alkali and alkali-earth metals, which react with the ferrous oxide, producing complex silicates of low melting temperature. These silicates are able to penetrate between sand grains and form a burnt-on skin. The use of molding sands with a minimum content of oxides of alkali and alkali-earth metals permits decreasing the burnt-on effect.

The intensity with which burning-on builds up also depends on the composition of a gas medium around the casting. Creation of the desired gas medium is one of the means of burning-on prevention. The protective medium for iron and copper-alloy castings is a reducing atmosphere. In molding iron castings, carbon-containing substances such as black oil (mazut) and coal dust (sea coal) are added to molding sand. As they disintegrate under the heat of metal, these substances produce a reducing gas medium in the mold. For steel

castings, it is an oxidizing atmosphere that produces a favorable effect. The molding sand must contain in this case manganese ore, vanadium pentoxide V_2O_5 , and other additives.

To facilitate stripping of adhered sand from the casting, the surface of the mold and cores is coated with antipenetration materials. Thus, in preparing molds for large steel castings, chromite-base paints make suitable mold facings. Chromite ground to powder and screened through a sieve of a mesh size of 1×1 mm must contain not less than 36% chrome oxide. The facing suspension contains (in percent by volume) 88% chromite, 10 to 12% molasses, and 2% dextrin, water being added in an amount enough to obtain the desired viscosity. The mold surface is given a coat of wash in a layer of 1.5 to 4 mm in thickness, and then dried at 360 to 380°C.

To prevent the sand from adhering to the surface of iron and copper-alloy castings, molds and cores are coated with a graphite or graphite-coke blacking. An addition of coke or graphite to a facing excludes the formation of oxides on the casting surface.

Mechanical penetration is the penetration of molten metal between sand grains into the surface layer of molds and cores under the pressure of the metal during its pouring and solidification. Here the metal itself serves as a bond for the layer of sand adhering to the casting. This layer is difficult to remove from the casting surface as it turns into a strong skin consisting of the molding sand saturated with metal (sand-metal mixture). Deep metal penetration presents a problem—castings are hardly amendable to machining since common cutting tools break off or wear out fast.

The degree of metal penetration depends on the properties of the metal cast, its overheating and density, properties of the mold, and the casting design. The lower the viscosity of a metal and the higher its specific heat, heat of crystallization and pouring temperature, the greater is the danger of metal penetration into the sand.

Metal penetration and burning-on can be eliminated by taking the following measures:

- (1) lowering the pouring temperature of metal;
 - (2) choosing the molding sand of appropriate grain size and properly ramming the working surface of the mold;
 - (3) dusting (for iron castings) the surface of green-sand molds with sea coal which gives off gases during iron pouring, the pressure of the gases keeping the melt from penetrating into the sand;
 - (4) applying to dry-sand molds antipenetration paints or washes which decrease surface porosity (see Table 18);
 - (5) diminishing the size of pores or voids in molding and core sands by adding fine-grained high-silica sand and ground quartz.
- To prevent mechanical metal penetration in large steel castings, use is made of facing sands with an addition of chromite screened through a sieve of 3×3 mm mesh size.

1.3. CRYSTALLIZATION OF ALLOYS IN THE MOLD

A metal poured into the mold begins to crystallize as it cools down. Crystallization is the process of growth of crystals (grains) during conversion of an alloy from the liquid or gaseous state to the solid state and also during transition from one phase to the other in the course of cooling of the solidifying alloy. The formation of crystals as the metal converts from liquid to solid is called *primary crystallization*, and a change in the form of crystals in the solid state is known as *secondary crystallization*. Primary crystallization determines the course of secondary crystallization, so the former is an important factor governing the mechanical and other properties of castings. So that the crystals may develop in the melt, this must have nuclei or centers of crystallization. Under definite conditions, each crystal begins to grow from a nucleus. Nuclei differ in the nature of origin. Some nuclei develop spontaneously in a super-cooled melt during its fast cooling: in the liquid state, atoms move in a random fashion, and as the free energy decreases (the alloy becomes solid), the atoms are able to merge into groups of a certain critical size and thus turn into centers of crystallization. Other nuclei are impurities always present in the melt. These are the products of reactions occurring in the furnace crucible and on the surface of lining.

For crystallization to begin, it is necessary to decrease the free energy, that is, to overcool the melt by removing some amount of heat and initiate the growth of crystals from the nuclei present in the melt. The melt overcools much more quickly (and thus has the largest quantity of nuclei) near the mold walls, so that a casting always begins to solidify from the mold walls inwards.

Growth of a primary crystal. A crystal will grow from a nucleus if the alloy goes on cooling down. The form and internal structure of the primary crystal depend on the rate of cooling, interfacial tension at the boundary between the solid and the liquid phase, and on the number of active nuclei per unit volume of the melt.

The greater the number of nuclei, the smaller in size will be the crystals, and vice versa. Because the alloy cools fast on the outside of the casting, the nuclei will grow into fine crystals. In the medium portion, where cooling is slow, the conditions are more favorable for free growth of columnar (fringe) crystals toward the center of the casting. In the central portion, nuclei will grow into large-sized, randomly oriented, equiaxed crystals.

Since a large number of factors influence the process of primary crystallization, the resultant structure of a casting will feature a certain kind and mutual arrangement of crystals in the solid alloy. Thus, the structure of a solid casting produced in a sand or metal mold may have the crystals of three kinds: columnar or dend-

ritic, with a parallel arrangement of principal axes; globular, of a rounded or hexahedral form; and mixed crystals with randomly oriented axes (Fig. 143a).

If columnar crystals extend to the axis of symmetry of the casting's cross section, they form what is called a transcrystalline structure (Fig. 143b); the process responsible for the formation of such a structure is known as *transcrys-tallization*.

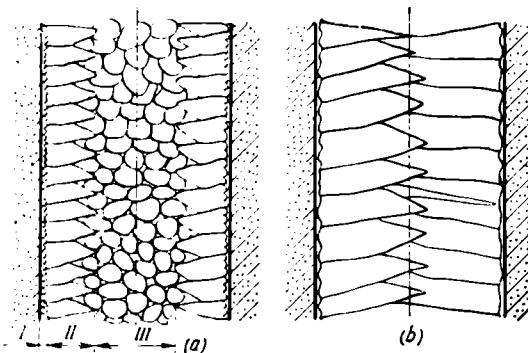


Fig. 143. Crystalline structure of a casting
(a) normal; (b) after transcrystallization

By the size of crystals, we can differentiate fine-grained and coarse-grained structures.

Castings whose structure consists of fine globular crystals show the highest strength and plasticity; castings with a columnar crystalline or transcrystalline structure are inferior to the above castings in strength and plasticity.

In shaped castings, three kinds of crystals are commonly present. Outside zone I (see Fig. 143a), near the mold walls, consists of globular grains and, sometimes, of acicular crystals; medium zone II consists of dendrites; and central zone III is composed of equiaxed, randomly oriented crystals. Steel and iron castings have a developed zone of mixed crystals, and nonferrous castings feature all the above zones. This structural difference is due to the composition and properties of the alloy cast.

The structure of castings is a function of a large number of factors, the basic ones being the properties of charge materials and conditions of melting, solidification range, impurities in the alloy, methods of pouring the melt into molds, cooling conditions of castings, and factors of mechanical nature which affect the process of crystallization.

Effect of the properties of charge materials and melting conditions. The basic constituents of charge materials almost completely pass into the melt, for which reason the crystalline structure of a casting depends on the composition and condition of the charge, heat schedule of melting, and the degree of metal deoxidation. It has been found that steel castings have the most favorable crystalline structure if the run proceeds with an intensive boil of the bath or the metal undergoes thorough refining.

Effect of solidification range. Academician A. A. Bochvar has ascertained that in alloys with a narrow solidification range (that is, with a small difference between the liquidus and solidus temperatures) it is columnar crystals that form most often. In alloys with a wide solidification range, randomly arranged dendrites commonly appear. This is the reason why castings from pure metals, low-carbon steels, brasses, and white iron have a developed zone of columnar crystals.

Effect of impurities. Academician A. A. Baikov has found that insoluble impurities contained in the melt are the centers of crystallization if the impurity crystal lattice constant is close in value to the lattice constant of the alloy base. Where this is the case, an alloy has a fine-grained structure and improved properties. However, heating the melt above a certain temperature tends to deactivate the impurity.

An understanding of how impurities influence the course of crystallization in castings offers a means for changing in the desired manner the crystalline structure of an alloy, that is, modifying it to improve its properties.

Effect of modification. *Modification (inoculation for cast iron)* is the treatment of molten alloys with special substances (modifiers) added to the alloys in small amounts prior to pouring into molds with the aim to refine the grains during primary crystallization. Modification gives a dense and homogeneous structure to castings.

There is modification of the first and the second kind. In carrying out modification of the first kind, the modifier, which is a surfactant, impedes further growth of grains and thus favors the formation of a fine-grained structure. During modification of the second kind, the modifier employed increases the number of nuclei. Examples of such modifiers added to steel to produce the above effect include boron, aluminum, and other elements.

Effect of pouring and cooling conditions. The metal poured into a mold gives up heat to mold walls. Near the runner, however, the metal heats up the mold walls more strongly, so that by the end of pouring the metal temperature in one portion of the mold differs from that in another. Obviously, since the portions of a shaped casting have different thermal conditions of crystallization, they will vary in crystalline structures. Thin sections of the shaped casting

will have a globular structure of crystals, and massive sections a dendritic structure. As the rate of primary crystallization rises, the size of crystals diminishes. That is why castings produced in metal molds are noted for a fine-grained structure. The pouring temperature has a profound effect on the size of grain. As this temperature drops, the grain size diminishes.

Effects of mechanical nature. D. K. Chernov has pointed out that there are possibilities for controlling the growth of crystals in an ingot, for instance, by turning it over during solidification or stirring the still liquid volume of metal in the ingot. Under the action of mechanical force, the growing dendrites in the alloy being crystallized break up into fragments, which may serve as additional nuclei altering the structure of the casting. This principle underlies such methods of control of crystal growth in castings as vibration of molds, electromagnetic stirring, and others. These methods enable the production of shaped castings with a fine-grained structure from alloys prone to transcrystallization.

1.4. INTERNAL CASTING STRESSES

As they cool and solidify, castings experience the action of internal stresses which arise from metal shrinkage. These stresses can lead to warping of castings and sometimes to hot and cold cracking.

One of the basic causes responsible for the appearance of cracks in castings is the retarding effect of the mold on metal shrinkage. As it contracts, the casting brings pressure by all its projections to the core or mold itself. The mold in turn retards the shrinkage of metal, causing stresses in the casting. The magnitude of these stresses depends on the deformability of the mold and cores. The higher the deformability of the mold and core, the lower the stresses and the smaller the probability that cracks may appear in the casting. If the stress exceeds the ultimate strength of the casting alloy in a certain portion of the casting, then a crack is likely to appear in that portion. If the alloy of a casting has sufficient strength and plasticity and is able to stand up to the effect of growing stresses, the shape of the casting distorts, and the casting twists and warps.

Hot tears (cracks) in castings arise at a temperature close to the solidus temperature. The stress in a mold may be found by the formula

$$\sigma_m = E_m \delta_m$$

where E_m is the modulus of elasticity of sand; δ_m is the deformation of sand.

Let us introduce the following designations: $T_1 - T_2$, the temperature range within which stresses appear; F_m , the bearing area

of a mold (Fig. 144); f , the cross-sectional area of a casting; α , the coefficient of thermal contraction of casting metal.

Now determine the relationship between the stress in a casting and the strain on it

$$\delta = \alpha(T_1 - T_2) - \delta_m$$

$$\sigma = E[\alpha(T_1 - T_2) - \delta_m] \quad (16)$$

The condition of equilibrium in the mold is expressed through the equation

$$E_m \delta_m F_m = \sigma f$$

whence

$$\delta_m = \frac{\sigma f}{E_m F_m}$$

Substituting δ_m into formula (16), we have

$$\sigma = E \left[\alpha(T_1 - T_2) - \frac{\sigma f}{E_m F_m} \right]$$

Solving the above equation for σ , we obtain

$$\sigma = \frac{\alpha(T_1 - T_2)}{\frac{1}{E} + \frac{f}{F_m} \frac{1}{E_m}} \quad (17)$$

From formula (17) it follows that shrinkage stresses in a casting (resulting from mold resistance) depend on physicomechanical properties of the casting and mold in the given temperature range and on the ratio f/F_m .

Contraction cracks commonly appear in casting portions where the rate of solidification is low, that is, in hot spots (see Fig. 144b).

Assume the casting has a hot portion of length l . In this case, all the casting will undergo deformation during contraction because of the presence of the hot spot. So, we must determine stresses precisely in this hot spot because it is subject to deformation due to nonuniform cooling. Denote the length of the casting exclusive of the hot portion by $L_1 = L - l$. The absolute deformation of the colder portion of the casting may be found from the formula

$$\epsilon_0 = \alpha L_1 (T_1 - T_2)$$

and the absolute deformation of the hot portion may be expressed as

$$\epsilon_h = \alpha l (T_1 - T'_2)$$

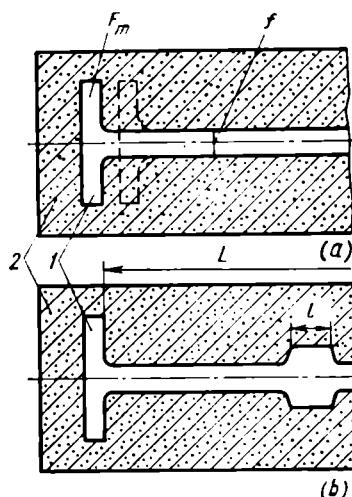


Fig. 144. Relating to the calculation of stresses in a casting with retarded contraction

(a) at uniform wall thickness; (b) in the presence of a hot spot in the casting body;

i—casting; *s*—mold

where T'_2 is the temperature of the hot portion of length l at the moment when the main portion of the casting has cooled down to T_2 ; in which case, $T'_2 > T_2$.

The total absolute deformation of the casting is

$$\epsilon = \epsilon_0 + \epsilon_h = \alpha L_1 (T_1 - T_2) + \alpha l (T_1 - T'_2)$$

Since this deformation is attributable to the effect of the hot portion, the strain on this portion will be

$$\delta = \frac{\epsilon}{l} = \frac{\alpha L_1 (T_1 - T_2)}{l} + \alpha (T_1 - T'_2)$$

According to equation (17), the stress σ in the hot portion of length l and cross section f_1 may be calculated by the formula

$$\sigma = \frac{\alpha \left[\frac{L_1 (T_1 - T_2)}{l} + (T_1 - T'_2) \right]}{\frac{1}{E} + \frac{f_1}{F_m} \frac{1}{E_m}} \quad (18)$$

Substituting $L_1 = L - l$ into formula (18) and performing the required transformations, we obtain

$$\sigma = \frac{\alpha \left[\frac{L}{l} (T_1 - T_2) - (T'_2 - T_2) \right]}{\frac{1}{E} + \frac{f_1}{F_m} \frac{1}{E_m}}$$

From the last formula it is obvious that the stress in the hot portion is almost directly proportional to the length of the casting. Consequently, the longer a casting, the higher the probability that cracks may develop in it.

It follows from the above that the formation of shrinkage cavities and cracks depends on the value of δ_m ; at $\delta_m = \alpha (T_1 - T_2)$, which condition presupposes that if the mold is absolutely yieldable, the stress in a casting will be absent.

Hot tears show up as narrow irregular crevices whose walls are covered with dark or colored oxide spots. The irregular shape of cracks is due to the fact that fissures mostly pass along the grain boundaries, and the dark color (or temper colors) of walls is the result of metal oxidation at high temperatures. Hot tears largely appear in thickened sections, at the places where massive sections pass into thin sections.

Certain impurities, gases, and nonmetallic inclusions are responsible for the enhanced tendency of alloys to develop hot cracks.

To exclude hot cracks in castings, it is good practice to observe the following rules:

1. Adhere strictly to the chemical composition required of the given alloy.

2. Avert the causes responsible for the retarded shrinkage of the casting during cooling in the mold, for which purpose it is necessary to employ deformable molding and core sands with organic additives which burn out and render the mold and cores more porous, or to resort to shell molds and cores.
3. In designing castings, see to it that massive sections smoothly pass into thin sections; in other words, avoid abrupt junctions.

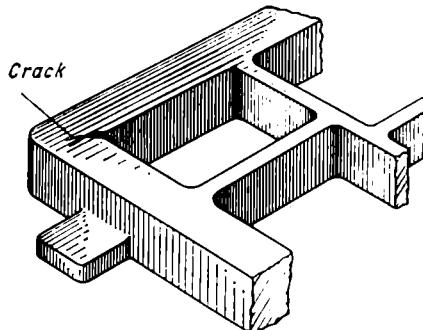


Fig. 145. Shrinkage crack in the frame casting

4. Secure uniform cooling of thick and thin sections of the casting with the aid of chills.
5. Use gates and risers which rule out local overheating of the mold and casting.
6. Use reinforcing (shrinkage) ribs to add to the strength of massive casting members which are inherently subject to cracking (in the fettling operation these ribs are chipped off).

Stresses in castings tend to arise not only from resistance the mold offers to metal, thus impeding contraction, but also, rather often, from the thermal retardation of shrinkage. For example, in the casting of a massive iron frame (Fig. 145), thin ribs that are the first to solidify oppose contraction of the massive shaping bar which solidifies some time later. At the frame corners, which solidify last, cracks are likely to form because tensile stresses develop in the frame fringe and compression stresses in the ribs.

Stresses arising from mechanical and thermal retardation of shrinkage are not always liable to produce cracks in castings. But then these stresses often lead to warping of castings, which defect can also cause rejection of the cast pieces.

Castings are subjected to heat treatment to relieve stresses. Iron castings are heated to 850-900°C and then cooled but slowly to guard against large differences in temperature between thick and thin sections. Heating tends to deform the stressed portions, thereby decreasing stresses. As-cast beds for precision machines are often subjected to natural aging (holding for a few months at the store).

combined with periodic machining of the castings. First, the castings are rough-machined, with a certain amount of stock left for subsequent machining, and then delivered to the store to be kept there for some time, following which the castings are machined again. The cycle is repeated several times. In the time intervals between machining operations, the distribution of stresses alters so that they decrease in magnitude. Apart from natural aging, in use is artificial aging which involves heating (to 500-550°C) and then slow cooling of castings.

Chapter 2. CASTING PROPERTIES OF METALS AND ALLOYS

The casting properties of metals and alloys show up during pouring into molds, crystallization, and further cooling of the castings.

Among most important casting properties of metal are fluidity (flowability), shrinkage (volume and linear), and tendency to segregation, hot cracking, gas absorption, and gas porosity.

2.1. FLUIDITY

Fluidity, or castability, of a molten metal is its ability to fill the mold cavity freely and evenly and thus produce the desired shape of the casting. A metal of good fluidity gives dense high-quality castings with decreased gas and shrinkage porosity, and excludes misruns and other casting defects. The fluidity of a metal depends on its viscosity and surface tension. The other factors that influence its fluid life are the impurity content, tendency to oxidation, and heat-transfer capacity of the casting mold. Almost all metals and alloys show a decrease in fluidity with growing viscosity.

Viscosity of alloys is a dynamic property by virtue of which they exhibit resistance to flow as a result of mutual friction of alloy particles in motion. The unit of viscosity is the poise. The viscosity of an alloy is a function of its composition, temperature, and the amount of impurities. Thus, solid inclusions and deoxidation products raise the viscosity of an alloy, while liquid nonmetallic inclusions, whose melting point is below that for the base metal, decrease its viscosity.

The viscosity of the same alloy may vary with the methods of metallurgical treatment employed. For example, a steel deoxidized with slag has a lower viscosity than a steel treated with such deoxidizers as ferrosilicon and aluminum. An increased viscosity of the melt is often responsible for rejection of castings due to short run.

As the temperature of melt grows, its viscosity diminishes, while its fluidity correspondingly rises. On the contrary, as the temperature of melt decreases, its viscosity goes up, and does so very intensively at a temperature below the liquidus line.

According to professor Yu. A. Nekhendzi, the zero fluidity (when the melt stops flowing at all) sets in if the solid phase accounts for 30% of the iron melt. For steels, the percentage is lower, 20%.

Surface tension is an important characteristic of a liquid alloy. With an increased surface tension, the alloy becomes less fluid and poorly fills thin channels.

So that an alloy will fill in the mold quite readily, it is good practice to disintegrate oxide films by chemical means. In casting iron pieces, for example, petroleum or kerosene sprinkled on to the mold's working surface ensures the desirable effect: petroleum disintegrates under heat and produces a reducing atmosphere in the mold.

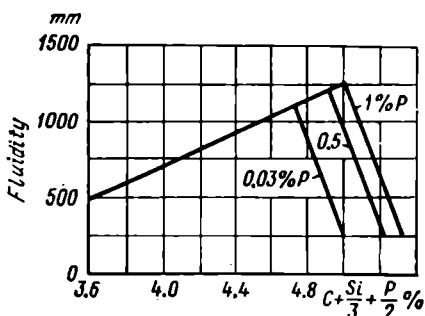


Fig. 146. Carbon, silicon, and phosphorus *versus* iron fluidity

Effect of mold properties. During pouring, the mold walls take off heat from the melt. The ability of a mold to transfer heat from the melt depends on its heat storage capacity b_m (see p. 62).

The sand mold removes heat slowly, so that the melt fills it better than the metal mold (the latter intensely cools the incoming melt). As the melt flows into the mold, it rubs against the mold walls. The coefficient of friction of the melt against the mold decreases with a decrease in the roughness of mold walls. This is particularly the case if a gaseous film produced from the burnt coat of wash or antipenetration powder covers the mold surface. If the mold contains more gases than enough to produce a gaseous film on the surface of contact, while the gases and vapors cannot freely escape, then a counterpressure is building up in the mold. This occurrence can be avoided by setting up flowoffs on all projecting members of the casting.

Effect of the chemical composition. The fluidity of iron grows with an increased content of silicon, phosphorus, and, in particular, carbon, and reaches a maximum (for eutectic irons) as the total content forms the sum $C + \frac{1}{3}Si + \frac{1}{2}P$ (Fig. 146).

Phosphorus increases the fluidity of iron, decreases its surface tension and viscosity, and produces a low-melting point phosphide eutectic. An increased content of phosphorus (to 1-1.5%) is vital to art castings for they require enhanced fluidity. Sulfur and manganese, each taken separately, have a weak effect on fluidity, but when these two elements are present in iron, they combine to yield manganese sulfide which heavily reduces iron fluidity. On the constitution diagram for Fe-Fe₃C, low-carbon pearlitic cast iron (2.8-3% C) lies farther from the eutectic (4.3%) than high-carbon iron (3.5%),

therefore the former has a lower fluidity than the latter. White cast irons are inferior to pearlitic irons in fluidity, because they lie still farther from the eutectic as regards their composition. Nickel and copper increase but weakly the fluidity of low-alloy cast irons, while chromium, molybdenum, and titanium decrease iron fluidity.

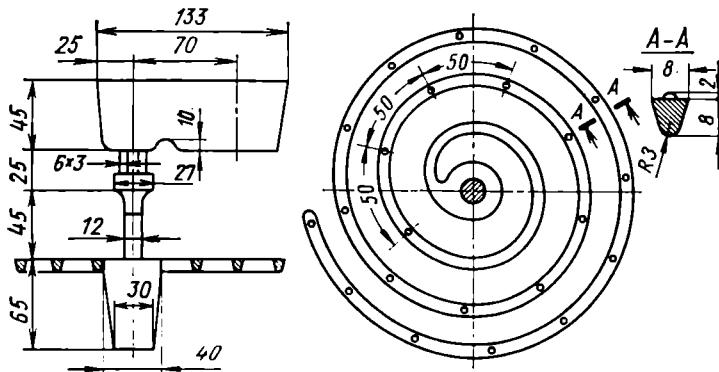


Fig. 147. Iron fluidity test specimen

Fluidity test. The ability of a liquid alloy to fill the mold should be considered as a complex casting property because this characteristic strongly depends on a number of factors such as the properties of the alloy, properties of the mold, and configuration of its cavity. The test for determining the fluidity of alloys consists in casting special fluidity specimens in the form of thin rods, straight plates, and spirals. The measure of the fluidity of an alloy is the path the molten alloy travels along the channels in the standard mold (that is, the length of the rod or plate cast). Test spirals (Fig. 147) of trapezoidal cross section, 0.56 cm² in area, are often used to assess the fluidity of irons. The length of the spiral cast characterizes the fluidity of the alloy under test.

2.2. SHRINKAGE

Shrinkage is the property of metals and alloys by virtue of which they decrease in volume on solidifying and cooling. Two basic types of shrinkage are distinguished, linear (ε_l) and volume (ε_v), which are expressed in relative values:

$$\varepsilon_l = \frac{l_m - l_0}{l_0} 100\%$$

$$\varepsilon_v = \frac{V_m - V_0}{V_0} 100\%$$

where l_m is the linear dimension of the mold, l_0 is the size of the casting at 20°C after solidification, V_m is the mold volume, and V_0 is the volume of the casting at 20°C.

Linear shrinkage. There are special testers for determining linear shrinkage, one of which is shown in Fig. 148.

Linear shrinkage of metal starts somewhat earlier than when the casting solidifies completely; it begins as soon as the neighboring crystals combine to form a crystal skeleton strong enough to stand

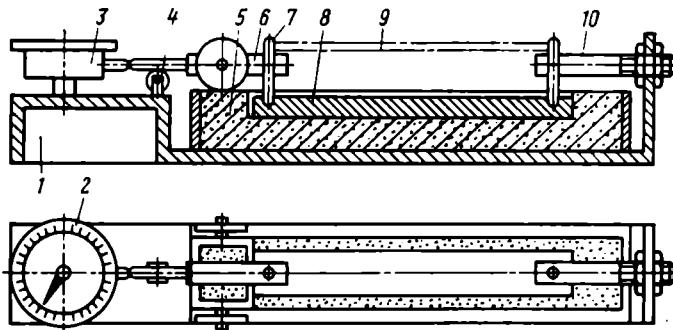


Fig. 148. Linear shrinkage tester

1—case; 2—dial; 3—indicator head; 4—roller; 5—mold; 6—carriage; 7—pin; 8—test bar
30 × 25 × 175 mm; 9—check plate; 10—retainer

up to the pressure of the liquid metal. So, the temperature at which a casting begins to contract in linear dimensions will be the temperature lying somewhere between the liquidus and solidus. Only in pure metals does the onset of linear shrinkage occurs at the critical temperature.

With the growing rate of heat transfer, the linear contraction of a casting increases; in other words, it depends on the rate of cooling of the casting.

Some metals and alloys undergo phase transformations such as graphitization in iron, gas evolution in steel, and others. These transformations tend to enlarge the casting in size and volume, leading to what is called *preshrinkage expansion*.

Preshrinkage expansion has a substantial effect on contraction of high-carbon alloys (when they undergo graphitization) and also of many grades of alloy steels and medium- and high-carbon steels. If preshrinkage expansion is intensive, the alloy becomes less prone to cracking and shrinkage porosity.

Casting shrinkage. This is the difference (expressed in percent) between the linear dimensions of the pattern l_p , and the casting, l_c

$$\epsilon_{c,sh} = \frac{l_p - l_c}{l_c} 100\% \quad (19)$$

Casting shrinkage differs from linear shrinkage in that the former depends not only on the properties and condition of a metal and alloy, but also on the design of a casting and mold, and on some other factors.

Intricately shaped castings are subject to the joint effect of mechanical and thermal retardation of contraction, for which reason it is common to differentiate between *free* and *impeded shrinkage*.

Shrinkage of iron. As molten iron cools down, its volume decreases. At the same time, the iron undergoes graphitization which tends to increase its volume.

Shrinkage of iron (usually determined as linear shrinkage) occurs in a few stages (Table 35, Fig. 149) which include: preshrinkage expansion ϵ_{ex} , prepearlitic shrinkage ϵ_p , and postpearlitic shrinkage ϵ_a . Also, calculations call for determining total shrinkage ϵ_t and effective shrinkage ϵ_e . In iron, ϵ_{ex} depends on the process of graphitization, that is, on the amount of graphite liberated in the solid mass of metal during its solidification. The other factors which affect ϵ_{ex} are the pressure of liquid metal on the solid mass and liberation of graphite in the liquid part of the casting.

Free shrinkage is largely a function of the composition of iron and the rate of cooling. It decreases with growing contents of carbon and silicon and with the increased thickness of a casting. In this

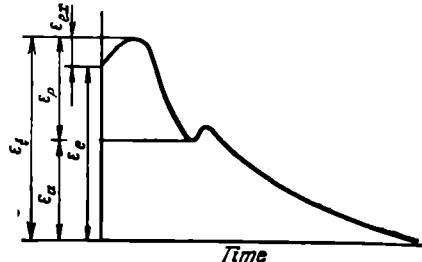


Fig. 149. Iron linear shrinkage curve

Table 35

Linear Shrinkage of Irons at Various Solidification Stages, %

Iron	ϵ_{ex}	ϵ_p	ϵ_a	ϵ_e	ϵ_t
White	0.1	0.6-1.0	0.9-1.05	1.5-2.2	1.5-2.1
Gray	0.1-0.25	0.2-0.35	0.9-1.05	0.9-1.3	1.1-1.4
High-strength:					
P+G,					
P+F+G,					
P+C+G	0.2-0.3	0.6-0.85	0.9-1.05	1.2-1.7	1.5-1.0

Note. P—pearlite; G—graphite; F—ferrite; C—cementite.

case postpearlitic shrinkage changes little and comes to merely 1%. Total shrinkage is the sum of prepearlitic and postpearlitic shrinkages. Effective shrinkage does not cover preshrinkage expansion. Where the effect of shrinkage retardation is strong, the total and the effective shrinkage of a casting correspondingly decrease.

Total volume shrinkage. This type of shrinkage, $\epsilon_{v.t}$, for any metal or alloy comprises liquid shrinkage $\epsilon_{v.l}$, freezing shrinkage $\epsilon_{v.f}$ (that is, solidification shrinkage occurring over the freezing range from the liquidus to solidus), and solid shrinkage $\epsilon_{v.s}$:

$$\epsilon_{v.t} = \epsilon_{v.l} + \epsilon_{v.f} + \epsilon_{v.s}$$

Volume shrinkage coefficients vary in value with different alloys. For liquid steel and copper, for example, this coefficient (per degree Celsius) is respectively 0.9×10^{-4} and 1.89×10^{-4} . The freezing shrinkage coefficient (per cm^3) is 0.034×10^{-2} for steel and 3.91×10^{-2} for copper.

2.2.1. SHRINKAGE CAVITIES

Shrinkage cavities in castings are voids resulting from shrinkage of alloys during solidification.

Figure 150 shows in schematic form how a shrinkage cavity develops in a shaped casting. As seen in Fig. 150a, thin walls are able to solidify and contract even in the process of casting the metal into the mold. The solid skin does not form soon after pouring because the inflow of fresh metal from gates and risers provides for feeding of the casting. The liquid metal then begins to contract inside the skin (Fig. 150b) as it cools to the temperature of the onset of crystallization or to the temperature of liquidus (Fig. 150c).

The rate with which the melt shrinks in volume as it passes from the liquid to the solid state exceeds the rate of skin contraction. So, at a certain moment the metal breaks away under gravity from the upper solidified skin and sags somewhat. In the next period, the liquid metal inside the solid skin begins to crystallize, in which process the metal shrinks so heavily that a cavity results (Fig. 150d). If the cavity does not contain gases, the rarefied atmosphere that builds up in it may cause the thin skin to sag down into the void (Fig. 150e). The means that effectively guard against the formation of shrinkage voids are risers set up on castings. The molten metal in the riser flows by gravity into a solidifying casting and compensates for shrinkage. The shrinkage cavity forms only in the riser to be subsequently cut off from the casting. Piping is inherent in castings from pure metals, alloys with a narrow solidification range, and eutectic alloys.

The relative volume of a shrinkage cavity differs with alloys. Thus, the shrinkage cavity volume in steel castings amounts to

3-10% of the initial volume of steel; for gray iron, inoculated iron, white iron, and nodular iron, the volume of shrinkage cavities is respectively equal to 1.5-2.5%, 2-3.5%, 2.5-6%, and 0-13%.

The relative volume of a shrinkage cavity may be calculated with the formula

$$V' = \epsilon_{v,l} + \epsilon_{v,s} - (\epsilon_{v,c} - \epsilon_{v,s})$$

where $\epsilon_{v,c}$ is shrinkage in the casting.

The volume of a shrinkage cavity depends on the following factors:

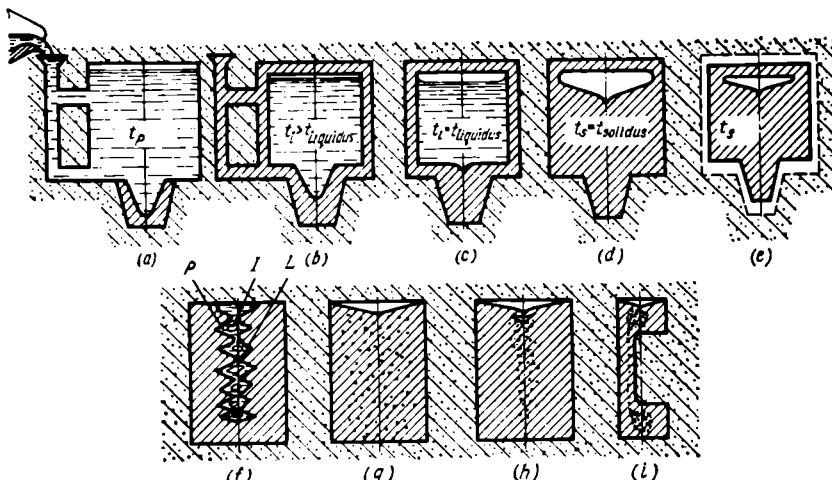


Fig. 150. Formation of a shrinkage cavity and porosity in castings

(1) the liquid shrinkage coefficient which varies with the chemical composition of metals and alloys;

(2) the temperature of a liquid metal or alloy at which it begins to solidify; the higher this temperature, the larger the volume of a shrinkage cavity;

(3) freezing shrinkage $\epsilon_{v,f}$, which is a function of alloy composition;

(4) the degree of graphitization of irons; the more graphitizing elements an iron contains (such as silicon, graphite, and others), the lower the shrinkage effect;

(5) the deformability of a mold and core; the more deformable the mold and core, the larger the degree of shrinkage, and vice versa.

2.2.2. SHRINKAGE POROSITY

Shrinkage porosity, or microporosity, is a concentration of small voids of an irregular shape within the casting material, which result from the volume shrinkage of metal in the absence of an inflow of

fresh melt. Shrinkage porosity is specific to alloys with a wide range of crystallization (Fig. 150f).

Shrinkage pores P appear in interdendritic spaces *I* when volume shrinkage is still going on while inflow of liquid metal *L* to the pores has ceased. During solidification, the growing dendrites combine to produce cells isolated one from another and from the riser. As the metal stops flowing to the cells, small voids appear, an aggregate of which gives shrinkage porosity.

There are various types of shrinkage porosity, such as diffused, axial, local, and others.

Diffused porosity (Fig. 150g) shows up as small voids almost uniformly dissipated over most of the casting bulk. This type of porosity develops during slow solidification of massive castings from alloys showing a wide solidification range.

Axial porosity (Fig. 150h) forms in axial portions of castings and also in long and thin sections. Its origin is due to the fact that, while the central part is still contracting in volume, the liquid alloy flows poorly, if at all, to it.

Local porosity (Fig. 150i) develops in casting portions isolated from the melt by the solidified alloy which obstructs the melt flow. Local porosity appears as a concentration of large-sized voids in massive sections and at the places where gates run into the casting.

2.2.3. WAYS OF ELIMINATING SHRINKAGE CAVITIES AND POROSITY

Shrinkage cavities and microporosity alter and weaken the cross section of a casting. These defects commonly appear in those sections of a casting which solidify last. Consequently, the only way of obtaining castings free from shrinkage voids is to feed the liquid alloy to the mold during the entire process of alloy solidification.

The flow of liquid metal to casting portions must be continuous until the casting solidifies completely. Risers placed on castings help accomplish the end. These are the reservoirs containing a sufficient amount of liquid metal for feeding the casting during the whole period of crystallization.

To effect correct feeding of a casting with liquid metal from a riser, one must provide for the following: (1) the amount of metal in the riser must be enough to compensate for shrinkage; (2) the riser must solidify some time later than the casting; (3) positioning of the riser on the casting must be such that the liquid alloy can get access to the casting sections which solidify last.

An effective way of producing dense castings without contraction voids is to secure conditions that initiate and control progressive solidification of metal first in the portions farthest from the riser, then in less remote portions, and, later, in the portions located just

under the riser, which must be the last portion of the casting to solidify.

With progressive solidification, the riser continuously feeds the portions of a casting since these portions directly receive liquid metal from the riser.

To improve the conditions of progressive solidification, it is necessary to exercise control over the direction of temperature gradients in a casting, that is, to promote the right abstraction of heat from its various portions by certain means, for example, by placing chills in the mold, which are massive metal inserts of increased heat capacity and thermal conductivity.

External chills (Fig. 189a) are placed at the massive portions of a casting. Owing to chills, heat removal from the massive portion of a casting proceeds more intensely than from the thin portion. This aids in equalizing the rates of freezing of the massive and thin sections, decreasing the volume of a shrinkage cavity or, in some case, eliminating this defect completely. Chills and risers placed on massive portions produce a joint effect which enables the production of castings completely free from contraction voids.

Internal chills (Fig. 189b) are inserted in mold cavities which form massive sections of the casting. These chills must be made from alloys whose chemical composition is the same as that of alloys of castings.

In pouring the mold, the metal washes over the chills, so that they partially melt and fuse with the metal. But sometimes internal chills poorly weld up with the base metal, therefore it is not advisable to use them in important castings. The methods of positioning various types of chills into mold are illustrated in Fig. 189.

In volume solidification, a casting crystallizes over the entire volume simultaneously, so that the casting develops microscopic voids rather than shrinkage cavities.

In intermediate solidification, both pipes and microscopic voids appear in castings.

To effect feeding of castings in the optimal conditions which exclude the formation of shrinkage cavities and porosity, it is good practice to resort to atmospheric pressure heads (blind risers with an atmospheric core), pressure heads (blind risers with a gas-producing charge), and exothermic sleeves, or to heat up risers, or to use various methods of physical influence, such as ultrasound, electromagnetic stirring, vibration, and so forth. These methods enable control of the processes of feeding of castings.

2.3. SEGREGATION

Segregation is the nonuniform distribution of alloying components, inclusions, and impurities in an ingot or casting, which arises during freezing. The cause of this phenomenon lies in a difference between

the solubilities of individual components of an alloy in its solid and liquid phases. The larger this difference, the more nonuniform is the distribution of an impurity over the cross section of the casting and, hence, the higher the degree of impurity segregation. In iron-carbon alloys, it is sulfur, phosphorus, and carbon that segregate most heavily. Segregation is responsible for the nonuniform mechanical properties of a casting in its various portions and may be the cause of rupture of the part when in service.

The basic types of segregation are microsegregation and macrosegregation. **Microsegregation** is an interdendritic segregation (coring) which shows up as chemical nonuniformity of individual dendrites in an alloy. It arises during what is known as selective crystallization: the arms of dendrites that are the first to grow in the course of solidification contain a smaller amount of impurities than the base alloy, so that the remaining liquid alloy proves more enriched in impurities. Impurities begin to concentrate in spaces between the arms of dendrites and bring about segregation inside the dendrites.

Macrosegregation is the zonal segregation of chemical constituents of an alloy in various portions of the casting during solidification. Along with the selective crystallization, the processes that cause segregating elements to move from one part of the casting to another have much bearing on the progress of this type of segregation. Thus, the processes conducive to zonal segregation may include diffusion of impurities from the two-phase zone of the solidifying casting within the still liquid alloy, convection of alloy streams in the liquid portion of the casting, floating of impurity-laden portions because they have a lower density than the base alloy, action of centrifugal forces, and others.

A variety of macrosegregation is **gravity segregation** in which alloying components that differ in density mechanically separate one from the other. This type of segregation often appears in high-lead bronze; during slow cooling, lead sinks into lower portions of the casting.

Macrosegregation may also manifest itself as a negative, or inverse segregation.

In the above types of zonal segregation, the axial portion of a casting becomes rich in impurities which lower the melting point of the alloy. The content of these impurities in the surface layers is below the mean content throughout the casting bulk.

In inverse segregation, the axial zone of a casting contains a smaller amount of low-melting impurities than in the outer parts. The development of either of the two types of macrosegregation is contingent on the character of alloy crystallization and conditions in which the casting solidifies. Common zonal segregation is typical of alloys subject to progressive solidification, and negative segregation, of alloys which solidify almost over the entire volume.

It is possible to overcome the effect of interdendritic segregation by subjecting the castings to annealing which balances out the content of impurities in individual dendrites. Heat treatment cannot correct the macrosegregation defect. To minimize macrosegregation, one should strive to make sections in a casting of a uniform thickness and avoid the formation of sections of extra mass at the junction of members, in which it is difficult to achieve uniform solidification and preclude the concentration of segregates. Since gating has a high effect on the progress of macrosegregation, it is helpful to feed metal to the mold at several places and thus balance out the rate of solidification of individual portions. Also, it is possible to produce the same effect by increasing the rate of metal cooling using for the purpose sand molds of high heat-storage capacity or metal mold. Alloys prone to macrosegregation should be poured at a minimum of overheat above the temperature of liquidus.

Part III

PRODUCTION OF GRAY IRON CASTINGS

Chapter 1. GRAY CAST IRON

1.1. GENERAL

Cast iron finds most extensive uses in foundry practice for the manufacture of cast shapes owing to its good casting properties and relatively low cost in comparison to other casting alloys.

Cast iron is a multicomponent alloy of iron with carbon (over 2%) and other elements; the liquid alloy composition solidifies on cooling to yield a eutectic.

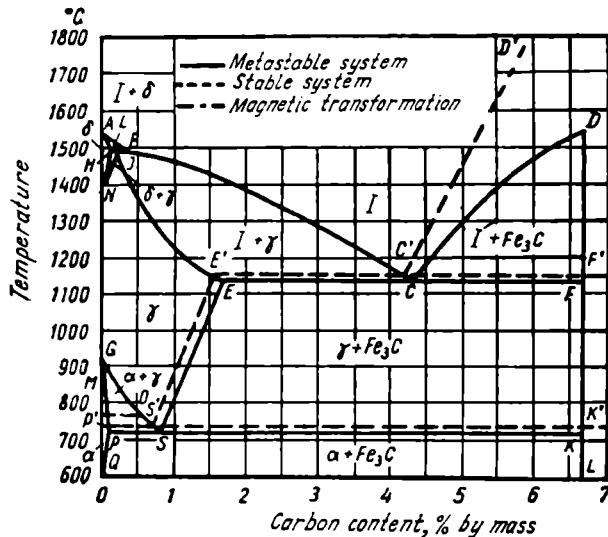


Fig. 151. Constitutional diagram of iron-carbon alloys

According to the iron-carbon diagram (Fig. 151), under the conditions of stable equilibrium, all carbon in iron separates out as graphite, and the metallic base as ferrite (gray cast iron); in the state of metastable equilibrium, all carbon separates out as iron carbide, or cementite, Fe_3C (white cast iron).

Gray iron contains carbon in the form of graphite and cementite present in pearlite. The properties of gray iron largely depend on the amount of graphite and pearlite, and also on the form and size of graphite inclusions. The inclusions of graphite weaken the cross section of the metal matrix (the principal phase) in a direction at right angles to an externally applied tensile force and also exert a notch effect on the metal matrix. Graphite reduces the tensile strength of iron; it also decreases the limit of elasticity and proportionality, plastic limit (elongation and impact strength), and modulus of elasticity. The adverse effect of graphite on these characteristics can be minimized by decreasing the number and size of these inclusions and by giving them the form that most closely approaches the form of a nodule.

In distinction to steel, iron shows a low notch sensitivity. The 'notches' found in cast iron parts, such as cravices, pores, nonmetallic inclusions, and marks formed in machining, decrease but insignificantly the structural strength of iron. This peculiarity of iron is due to the presence of a large number of notches resulting from graphite inclusions and to a high cyclic toughness.

1.2. EFFECT OF THE CHEMICAL COMPOSITION ON THE STRUCTURE AND PROPERTIES OF IRON

By the content of carbon, irons are classified as hypoeutectic, eutectic, and hypereutectic. During solidification of a hypoeutectic iron, it is the high-carbon phase (primary graphite or primary cementite) that separates out first. A eutectic solidifies at the temperature of eutectic melt. The composition of a eutectic and the temperature of eutectic transformation depend on the system (stable or metastable) in which this transformation proceeds. The structure of iron assumes the final form in the course of eutectoid transformation.

During crystallization of gray iron, the basic structural constituents present in the melt by the moment of eutectoid transformation are austenite and graphite. The latter appears during eutectic transformation as it separates from austenite on cooling in the temperature range extending up to the eutectoid transformation. In the course of eutectoid transformation, iron atoms regroup to form a body-centered cubic lattice (α -Fe structure) from a face-centered cubic lattice (γ -Fe structure) and graphite diffuses from iron. The resultant structures consist of ferrite and a high-carbon phase. Slow cooling gives carbon in the form of graphite. The final structure of iron will be of the ferrite-graphite type. In Fig. 151, the dash lines, which correspond to the liberation of graphite, represent the stable equilibrium diagram for Fe-C alloys; the solid lines correspond to the isolation of cementite. The characteristic points on the stable diagram are designated by letters with primes. The line $C'D'$ is representative of

the isolation of primary graphite, and the line $E'C'F'$ of the solidification of a graphite eutectic, which is a fine-grained mechanical mixture of austenite and graphite. Further cooling (down to the line $P'S'K'$) causes precipitation of a eutectoid mixture consisting of ferrite and graphite. Irons in which carbon appears either partially or fully as graphite are called ferritic because ferrite forms the matrix. Carbon separates as graphite only at a very slow rate of cooling. Very fast cooling results in cementite rather than graphite in the course of crystallization (both primary and secondary). With a further increase in the rate of cooling, the range of separation of the graphite eutectoid terminates short of the line $P'S'K'$, and the remaining carbon passes into cementite (along the line PSK), which brings about the formation of a certain amount of pearlite. Such an iron will have a structure consisting of ferrite, pearlite, and graphite inclusions.

With a yet further increase in the rate of cooling as far as the line $P'S'K'$, the graphite eutectoid does not appear, while austenite changes into pearlite (along the line PSK). The iron will have the base composed of pearlite and graphite inclusions in the form of flakes. Such an iron is called pearlitic.

When the rate of cooling becomes very high, cementite rather than graphite begins to separate from austenite before the austenite transforms to pearlite (the process occurs between the lines of eutectic and eutectoid transformations). This iron has a pearlite-secondary cementite-graphite structure.

The structure of iron sometimes contains, along with graphite, ledeburite (at an increased rate of cooling and with the eutectic transformation). Such an iron is called mottled. White cast iron does not contain free graphite at all; graphite occurs in the combined form, as a chemical composition of carbon and iron. The structure of white iron consists of pearlite and cementite.

Irons are considered eutectic if they contain 4.2-4.3% C. Given a large number of components, it is possible to form complex eutectics in a certain alloy system. For example, phosphorus (over 0.06-0.08%) forms with carbon and iron a phosphide eutectic solidifying at 950°C. The size and form of graphite inclusions depend on the centers of crystallization present in liquid iron, rate of cooling, and the content of graphitizing additives. The more insoluble small particles (nuclei) the molten iron contains, the finer will be graphite.

Inoculants such as graphite, silicon, calcium silicon, and aluminum added to molten iron before its pouring increase the number of nuclei. As the period of crystallization decreases and the content of graphitizing components in iron increases, the flakes of graphite become larger and longer.

The chemical composition of an iron largely determines its mechanical properties.

Silicon decreases the solubility of carbon in liquid and solid solutions and encourages graphitization, for which reason the increased content of silicon impairs the mechanical properties of high-carbon irons (because of the formation of large inclusions of carbon).

If the transformation takes place in a metastable system, the fraction of a eutectic in the structure of iron is found by the formula

$$S_e = \frac{C - 2}{4.3 - 2} = \frac{C - 2}{2.3}$$

where C is the carbon content of iron.

For an alloy free of silicon, $S_e = 1$, which corresponds to 4.3% carbon. For hypoeutectic irons, $S_e < 1$, and for hypereutectic irons, $S_e > 1$. The effect of silicon on the eutectic component of iron is expressed in terms of the carbon equivalent calculated in percent. Considering the silicon content of iron, the carbon equivalent $C_e = C + 0.3\text{Si}$. With allowance being made for the contents of silicon and phosphorus, $C_e = C + 0.3(\text{Si} + \text{P})$. Irons are considered eutectic if the eutectic equivalent is equal to 4.2-4.3%. Taking into account the effect of silicon and phosphorus, the eutectic component for iron may be determined from the expression

$$S_e = \frac{C}{4.3 - 0.3(\text{Si} + \text{P})}$$

With an increase in the carbon equivalent C_e , the amount of graphite rises, while the amount of pearlite and the degree of its dispersion decrease and the size of graphite inclusions grows, which lowers the strength of iron.

Manganese dissolves in ferrite and combines with carbon (yielding other carbides) and also with sulfur to form manganese sulfide, MnS; this increases the strength of iron and lowers its toughness. Manganese present in iron counteracts the harmful effect of sulfur.

Manganese reduces the temperature of the phase transition $\gamma \rightarrow \alpha$, expands the region of γ -solution and aids in the formation of a finer structure of pearlite. A manganese content of up to 15% has a favorable effect on the mechanical properties of gray iron.

Sulfur and iron combine to form a low-melting eutectic with a melting point of 985°C. Sulfur can dissolve in unlimited quantities in liquid iron, but insignificantly in solid iron.

Sulfur is present in the form of sulfides rich in iron or as a eutectic. Sulfur retards graphitization in low-manganese irons and impairs their mechanical properties as it forms brittle eutectic at the grain boundaries. To neutralize this effect of sulfur and thus reach a maximum degree of graphitization, the manganese to sulfur ratio must be equal to 4 or 5. In this case, sulfur will mainly be present as manganese sulfides which do not affect the process of graphitization.

Sulfide compounds increase the viscosity of liquid iron, reduce its fluidity, and impair mechanical properties. As the sulfur content of iron comes to 0.12-0.14%, the fluidity of liquid iron sharply decreases, the amount of cementite and pearlite in its structure grows, and hard (chilled) spots appear in this sections of castings. Hard spots occur when iron sulfides (which have a low melting point) crystallize on the boundaries of grains and impede the dissolution of carbon and silicon in the iron and disintegration of cementite.

Phosphorus reduces both the solubility of carbon in iron and the temperature of eutectic transformation. Phosphorus completely dissolves in iron if its content does not exceed 0.3%; as its content rises above 0.3%, phosphorus reacts with iron to yield a phosphide eutectic in the form of separate inclusions, $\text{Fe}_3\text{P}-\text{Fe}_3\text{C}-\text{Fe}$, which melt at 950°C. With a phosphorus content in excess of 0.6 or 0.7%, the phosphide eutectic is segregated as a continuous network at crystal boundaries. That is why the phosphorus content of iron for important castings must be under 0.15-0.20%; in castings designed for frictional work without impacts (where the antifriction requirements are stringent), the phosphorus content must be below 0.6 or 0.7%.

Phosphorus adds to metal fluidity, therefore the content of phosphorus in iron used for art castings is raised to 1% and over. It has an insignificant effect on graphitization.

Chromium appears to be a carbide-forming element during eutectic transformations and renders austenite more stable when eutectoid transformations take place. This metal gives iron strength by virtue of which it withstands elevated temperatures and multiple cycles of heating. Thus, chromium makes an essential additive in the composition of heat-resistant and scaleproof irons. Chromium raises the hardness and wear resistance of iron, resistance to the corrosive effect of sea water and weak acid solutions, but makes it more brittle. With a chromium content in excess of 0.8%, the strength of iron diminishes because of the formation of free chromium carbide.

Nickel present in iron-carbon alloys lowers the critical points A_1 and A_3 , shifts the critical points E and S to the left and downward, and slightly raises the temperature of eutectic transformation. Also, it adds to the stability of austenite, the solubility of carbon in liquid and solid solutions, and increases the carbon content of a eutectic and eutectoid. Nickel is a graphitizing element. It acts on the eutectic transformation in the same manner as silicon, but at the same time retards the disintegration of eutectoid carbides and thus stabilizes pearlite and increases its dispersity.

As the nickel content of iron exceeds 2%, the iron structure first becomes all-pearlitic and then sorbitic. A yet further increase in the amount of nickel to 4.5-5% results in martensite. Nickel raises the corrosion resistance of iron castings in sea water and in alkalies.

Copper readily dissolves in liquid iron if its content is under 3 or 4%. It encourages graphitization and decreases the iron hardness. In gray iron, copper contributes to the stabilization of pearlite and increases the hardness. Besides, it reduces the temperature of eutectic transformation and favors the formation of a more uniform structure in thin and massive sections of a casting. Decreasing the content of copper in high-carbon iron increases the hardness and strength. The optimal copper content of an alloy gray cast iron is 3 or 4%. Copper encourages graphitization as iron solidifies, but impedes the desintegration of pearlite during the eutectoid transformation. This metal increases the corrosion resistance of iron exposed to atmospheric conditions, in the solutions of salts, acids, and in petroleum.

Titanium lowers the temperature of eutectic transformation and promotes iron overcooling. An addition of about 0.5% titanium to a supoeutectic iron steps up graphitization and liberation of graphite in the form of small flakes. It is common practice to add no more than 0.05-0.1% titanium to iron; for the iron that goes into the production of piston rings, however, the percentage is high, 0.2%. Titanium is a good deoxidizer and aids in uniform distribution of graphite in iron. It neutralizes the effect of chromium in iron (serving in this case as an inoculant), thereby eliminating the need to increase the content of silicon. Titanium improves the mechanical properties of iron; in particular, it raises the strength of high-carbon irons. As its content exceeds 0.18-0.20%, titanium reacts with carbon to produce carbides which inhibit graphitization. Titanium serves as an inoculant in the production of malleable iron, but for high-strength iron castings this metal is an undesirable additive since it impedes the formation of globular graphite.

Molybdenum lowers the temperature of the beginning and end of austenite crystallization, reacts with cementite to form solid solutions and dissolves in iron when added in an amount of about 1.3%. At the cooling rates common to gray iron castings, molybdenum speeds up graphitization. With a molybdenum content of supoeutectic gray iron of up to 1%, the amount of cementite in the iron does not grow; with 3% Mo, graphitization slows down; and with a yet further increase in the amount of molybdenum, the iron solidifies white. Molybdenum increases the strength and hardness of supoeutectic irons. Besides, it raises the short-term strength of iron at high temperatures, thermal stability, resistance to thermal growth (growth in volume under heat), wear resistance, and impact strength. Molybdenum imparts high-temperature strength to iron; in this respect it surpasses all other elements.

1.3. CLASSIFICATION OF IRONS

White cast iron (Fig. 152) consists of pearlite and cementite, with carbon being present as an iron-carbon compound. It is very hard, brittle, and not amenable to machining, so that its uses in machine building are rare, largely limited to applications where the parts (such as stone crusher jaws, mill balls, railroad-car brake blocks) have to work in friction. The working skin of cast parts should have the structure of white iron, while the central portion (being the softest) the structure of gray iron. Such castings are called chill, or hard. White iron (both low-carbon and low-silicon grades) is also used for the production of malleable iron. The castings are produced in white iron, which are subsequently malleablized (that is, annealed to convert the combined carbon into graphite or free carbon).

Gray cast iron usually has flaky graphite and a portion of combined carbon. Inoculants such as magnesium or cerium added to liquid

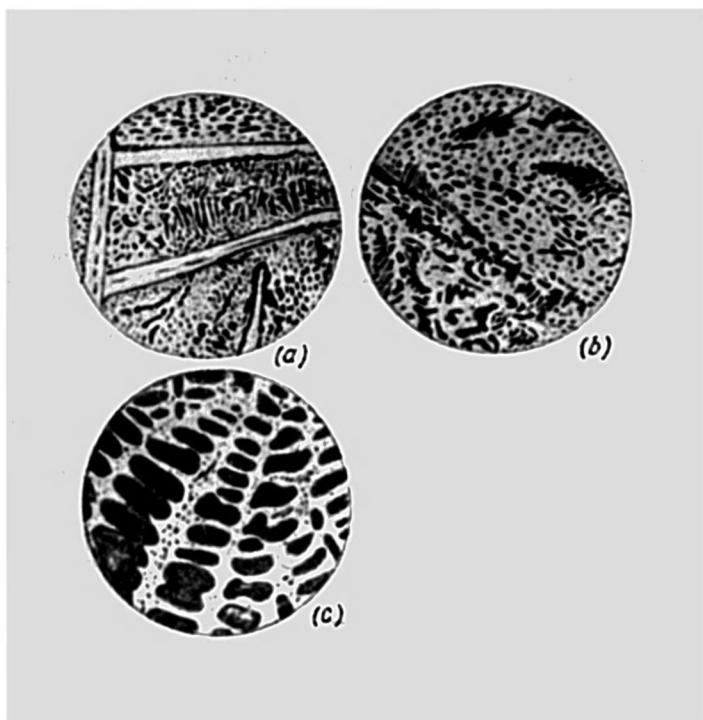


Fig. 152. White irons

(a) hypereutectic, $\times 50$; (b) eutectic, $\times 100$; (c) hypoeutectic, $\times 100$

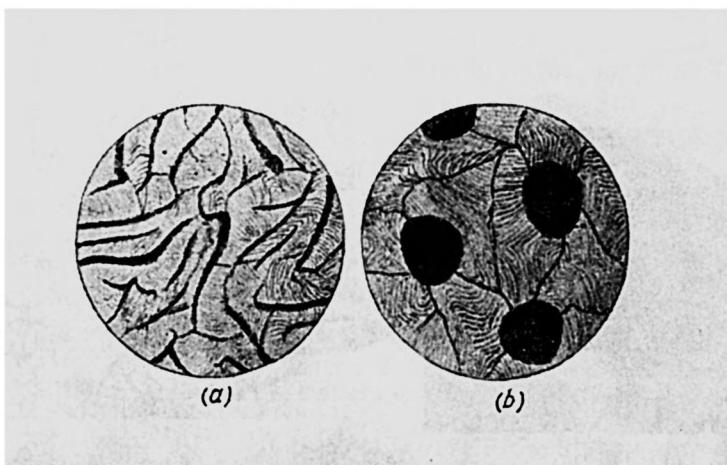


Fig. 153. Pearlitic gray cast iron

(a) flaky graphite, $\times 300$; (b) spheroidal (nodular) graphite, $\times 400$

iron stimulate the formation of globular (nodular) graphite in castings. By the composition of the basic metallic mass, gray cast iron may be of the four types.

Pearlite-cementite gray iron, which consists of pearlite, aggregates of cementite, and flaky graphite. Such a structure can be obtained by decreasing the silicon content of iron and sharply cooling castings in molds. Iron grades of this type show increased hardness and are difficult to machine. The use of cerium or magnesium as inoculants enables the production of a high-strength iron whose structure is pearlite, cementite and nodular graphite.

Pearlitic gray iron, which consists of pearlite and flaky graphite. Inoculation by magnesium or cerium (Fig. 153) gives the pearlitic structure with nodular graphite.

Pearlitic iron commonly contains fine flakes of graphite and shows moderate hardness (BH 200 to 230), high strength and wear resistance, and good machinability. Pearlitic gray iron with nodular graphite has a yet higher strength. It is called high-strength, or high-test, iron.

Pearlite-ferrite gray cast iron, which comprises pearlite, ferrite, and flaky graphite (Fig. 154). It is inferior to pearlitic iron in strength since the flakes of graphite in its structure are large. Because its hardness is lower than that of the above type, it machines more readily. This structure of iron is typical for common iron castings used in the machine-building industry.

Ferritic gray cast iron, which consists of ferrite and flaky graphite (Fig. 155). This structure appears in thick-walled castings high in silicon at the slow rate of metal cooling in molds. Graphite aggre-

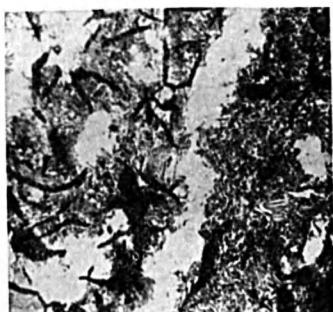


Fig. 154. Gray cast iron. Pearlite-ferrite structure



Fig. 155. Ferritic gray cast iron

gates are very large in size. Ferritic iron shows low mechanical properties, is very soft, brittle, wears out fast, but is easily machinable. It is unsuitable for castings used in machine building.

1.4. MECHANICAL PROPERTIES OF CAST IRON

Flake graphite iron is largely used for castings of machinery parts. The major consumers are automotive-tractor and allied industries. The quality of gray cast iron is assessed by its mechanical properties, some of which are given in Table 36.

Irons of increased strength (grades СЧ 24-44, СЧ 32-52, СЧ 36-56, СЧ 40-60) find use for cast parts designed to work under the conditions of intensive abrasive wear (I.C.E. parts, various cylinders, machine tool parts, and others) and also for massive parts whose working surfaces must have an enhanced hardness and definite microstructure of iron containing dispersed pearlite and fine inclusions of graphite.

The mechanical properties of an iron are determined from the tests performed on cylindrical cast pieces (rods) 30 mm across and 360 mm long, or on 25 mm square rods of the same length. Tensile-test rods are turned to rated diameters of 10, 15, 20, and 25 mm from separate workpieces. Tensile-test square rods are chosen depending on the casting wall thickness (Table 37). The normal test rod must be 20 mm in diameter. The shortened length of a specimen must be 100 mm, and the normal 200 mm.

Table 36

Mechanical Properties of Gray Cast Iron Castings

Iron grade	Strength, MPa (kgf mm ⁻²)		Bending deflection, mm (support-to-support distance, 300 mm)	BH, MPa (kgf mm ⁻²)
	in tension	in bending		
Not subject to testing				
СЧ 00				
СЧ 12-28	118 (12)	274 (28)	2.0	1 400-2 220 (143-229)
СЧ 15-32	147 (15)	314 (32)	2.5	1 600-2 200 (163-229)
СЧ 18-36	176 (18)	353 (36)	2.5	1 670-2 200 (170-229)
СЧ 21-40	206 (21)	392 (40)		1 670-2 360 (170-241)
СЧ 24-44	235 (24)	430 (44)		1 670-2 360 (170-241)
СЧ 28-48	274 (28)	470 (48)	3.0	1 670-2 350 (170-240)
СЧ 32-52	314 (32)	510 (52)		1 830-2 500 (187-255)
СЧ 36-56	353 (36)	550 (56)		1 930-2 640 (197-269)
СЧ 40-60	392 (40)	588 (60)	3.5	2 010-2 640 (207-269)
СЧ 44-64	430 (44)	628 (64)		2 220-2 830 (229-289)

Table 37

Diameters and Cross-Sectional Dimensions of Gray-Iron Tensile-Test Specimens

Casting wall thickness, mm	Rod	Square rod	Casting wall thickness	Rod	Square rod
< 16	20	10	31-50	40	20
16-30	30	15	50-70	50	25

Irons of grades СЧ 28 through 48 and above are referred to as high-quality irons. They have a pearlitic structure with fine flakes of graphite. It is advisable to modify these irons by inoculation.

Gray iron of enhanced quality can be obtained without inoculation and alloying, for example, by introducing steel into the charge, overheating the iron, and holding the melt for some time before pouring it into molds.

1.5. INOCULATION OF GRAY IRON

Inoculation is a process of modifying the structure and properties of castings. Gray irons are inoculated to produce fine-flake graphite pearlitic irons and high-quality nodular cast irons. In producing malleable iron, this process speeds up annealing of white cast iron.

The inoculants used for the purpose are calcium silicon (0.3 to 0.8% by mass of molten iron), ferrosilicon (0.3 to 0.8), powdered crystalline graphite (0.06 to 0.1%), and others. Before being introduced into molten metal, inoculants should be calcined at 300-400°C and ground to a particle size of under 5 or 6 mm. Special feeders then charge inoculants on to the chute of the cupola or directly into the ladle. Casting into molds must begin the moment the inoculation is over to make the most of the modifying effect and keep the iron in the overheated state.

Inoculation in itself improves but little the properties of gray iron; it yields good results only in combination with other processes intended to overheat the molten metal, reduce the contents of carbon and silicon, and increase the manganese content to 1-1.5%. Overheating makes graphite finer and increases the amount of combined carbon. But this process leads to overcooling of the iron as it solidifies and thus to chilling, particularly in thin sections of castings. An increase in the silicon content with a view to preclude chilling in thin-walled castings promotes the formation of fine dispersed inclusions of graphite and ferrite, which is undesirable too. Inoculation, on the other hand, makes it possible to degassify the iron, create additional nuclei for crystallization, prevent it from overcooling, and thus greatly intensify the graphitization process and exclude the appearance of hard spots.

Inoculation increases the strength, wear resistance and tightness of gray iron, improves its thermal stability and workability.

1.6. HIGH-STRENGTH IRONS

These are cast iron grades modified by magnesium added in an amount of 0.15 to 0.45% and subsequently treated with ferrosilicon (75% Si). The inoculants change the condition of growth of a graphite nucleus, so that it turns into a spheroid, or nodule (see Fig. 153). The graphite of this form makes the iron stronger and much more plastic.

High-test cast iron offers the following advantages over carbon steel: a lower melting point, higher fluidity, decreased tendency to form hot and cold cracks, lower specific density, higher strength and wear resistance, and better machinability. In comparison with gray iron, it shows a higher strength, plasticity, thermal stability, and better weldability.

Magnesium adds somewhat to the fluidity of this iron, considering that all other conditions being the same (the chemical composition, pouring temperature, cooling rate, and others). The linear shrinkage of high-test cast iron is near 1.7 to 1.8%, which is higher than that for common iron; if it solidifies in the stable state, the high-test cast iron may have the same shrinkage as gray iron. Magnesium makes the iron more resistant to wear and corrosion. Since it cools heavily under the effect of this inoculant, the iron should be overheated to 1 400-1 450°C.

Cerium also serves as an inoculant for the iron. The ground cerium addition (0.2 or 0.3%) is made directly in the ladle when filling it with the molten iron. Cerium exerts the same effect on the form of graphite as magnesium. Under the influence of cerium, the nodules of graphite can be formed both in the hypoeutectic and the hyper-eutectic iron; in each case it is necessary to overheat the iron to 1 500°C. The casting properties and the strength of the cerium-treated cast iron are superior to those of the magnesium-treated iron, but since cerium is a critical metal, its uses are limited.

The iron modified by magnesium or cerium should be subsequently treated with ferrosilicon (75% Si) to control the structure of metal matrix. The ferrosilicon addition ground to particles 6 to 10 mm in size may be loaded together with magnesium. The amount of ferrosilicon put into the ladle is dependent on the iron composition, casting wall thickness, quantity of an inoculant (magnesium or cerium), and on other factors; it usually ranges from 0.3 to 1.2% of the mass of molten iron.

Magnesium is added to molten iron in the form of such compositions as Mg-Ni, Mg-FeSi, and others, or, sometimes, in the pure form. There are several methods of introducing magnesium and its alloys into the molten iron: by charging it into the ladle with a plunger, into the cupola forehearth, and into special air-tight ladles. The open method of loading the magnesium addition is performed at the atmospheric pressure, and the closed method at the excess pressure. Magnesium introduced into the iron vaporizes to yield a large quantity of white fumes, which reduce the iron temperature by 120 to 150°C. Special forehearths or air-tight ladles help remedy the situation. In the forehearth, the iron absorbs magnesium more intensely because magnesium evaporates here at 1400°C and the pressure of magnesium vapors runs as high as 785 kPa (8 kgf cm⁻²). Fig. 156 illustrates a method of controlled vaporization of magnesium introduced into a ladle. In this method developed in the Soviet Union, the molten iron is poured into a drum-type hermetically sealed ladle through a neck, the magnesium addition being put into the side holder beforehand. The pouring being over and the neck closed, the ladle is tilted to make the iron come into contact with magnesium. As magnesium evaporates, the pressure in the ladle

rises to 245-294 kPa (2.5-3 kgf cm⁻²). Since the iron intermingles with magnesium in a gradual manner, the absorption of magnesium in the ladle reaches 30 to 40%. A list of mechanical properties of

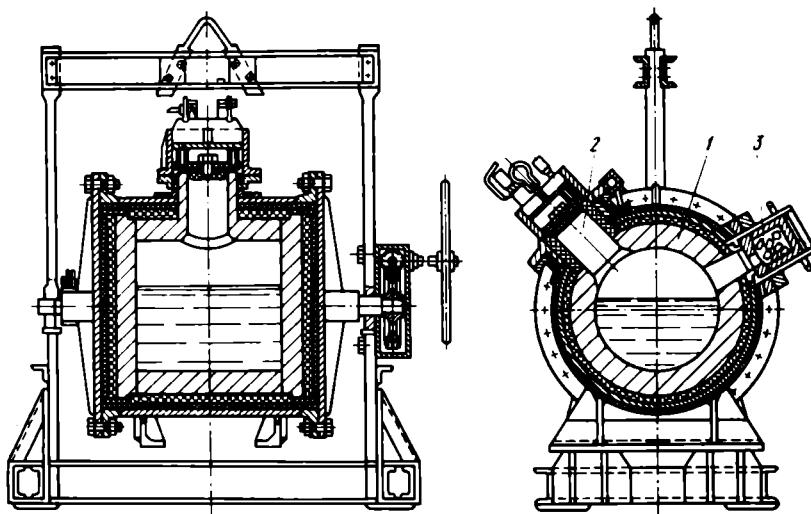


Fig. 156. Airtight ladle for treatment of iron with magnesium
1—ladle; 2—liquid iron filler neck; 3—magnesium holder

high-strength iron appears in Table 38. This type of iron is used in machine building for casting crankshafts, rolls, and other parts.

Table 38
Mechanical Properties of High-Strength Iron

Iron grade	Rupture strength, MPa (kgf mm ⁻²)	Yield limit, MPa (kgf mm ⁻²)	Relative elongation, %	Impact strength, kPa (kgf mm ⁻²)	BH, MPa (kgf mm ⁻²)
ВЧ 38-17	373 (38)	236 (24)	17	588 (6)	1 370-1 670 (140-170)
ВЧ 42-12	412 (42)	275 (28)	12	392 (4)	1 370-1 980 (140-200)
ВЧ 45-5	442 (45)	324 (33)	5	294 (3)	1 570-2 180 (160-220)
ВЧ 50-2	490 (50)	373 (38)	2	196 (2)	1 960-2 740 (200-280)
ВЧ 60-2	590 (60)	394 (40)	2	196 (2)	1 960-2 740 (200-280)
ВЧ 70-3	688 (70)	394 (40)	3	294 (3)	2 240-2 700 (229-275)
ВЧ 80-3	785 (80)	490 (50)	3	196 (2)	2 160-2 940 (220-300)
ВЧ 100-4	980 (100)	680 (70)	4	294 (3)	2 960-3 600 (302-369)
ВЧ 120-4	1 180 (120)	885 (90)	4	294 (3)	2 960-3 600 (302-369)

1.7. ALLOY CAST IRONS

Alloying elements improve the mechanical properties of iron and impart corrosion stability, wear resistance, high-temperature strength antifriction and other properties. By the contents of alloying elements introduced into iron grades, cast iron is classified under three types: low-alloy (up to 3% alloying elements), medium-alloy (3 to 10% alloying elements), and high-alloy (over 10% alloying elements). The alloying elements for iron are nickel, chromium, molybdenum, manganese, aluminum, copper, titanium, and others. In machine building, low-alloy irons have found most wide application.

Low-alloy structural irons. Chromium-nickel irons of various grades contain 0.3 or 0.4% Cr and 0.1 or 0.2% Ni. The charge is made with 8% iron having on the average 1% Ni and 2.5 to 2.7% Cr. An iron alloyed with 0.25 to 0.35% Cr and 0.25 to 0.35% Ni makes an excellent material for the production of I.C.E. cylinder blocks, brake drums, machine beds, and other important parts of the machine-building industry. Such irons have enhanced mechanical properties and good wear resistance.

In low-alloy irons, it is chromium that determines the effectiveness of alloying. Thin-walled castings made from an iron containing 0.3-0.4% Cr and 0.1-0.2% Ni are liable to chilling. The use of such inoculants as ferrosilicon, calcium silicon (silicocalcium) or graphite obviates the defect.

I.C.E. piston rings are produced from a low-alloy iron containing 3.8-3.9% C, 2.4-2.6% Si, 0.1-0.2% Cr, 0.15-0.25% Ni, 0.35-0.5% Cu, and 0.1-0.2% Ti. This iron grade is made from the charge whose composition includes an iron with small percentages of such alloying elements as chromium, nickel, copper, and titanium. Large brake drums of cars and aircraft are manufactured from an iron with 3.8% C, 1.35% Si, 2% Ni, 0.25-0.35% Cr, and 0.4-0.5% Mo. The strength in tension of this iron grade is up to 274 MPa (28 kgf mm⁻²). It features a homogeneous structure and machines easily.

Wear-resistant irons go into the production of heavy duty parts (bearings, cylinders, sleeves, brake drums, and so forth). To impart a high wear-resisting property to an iron, use is made of alloying elements (such as chromium and molybdenum) capable of producing wear-resisting carbides. The iron of the ni-hard type contains 2.7-3.6% C, 0.4-1% Si, 0.25-0.7% Mn, 3-5% Ni, 1.2-2.8% Cr, about 0.15% S and 0.4% P.

Wear-resistant iron is used for casting wire-drawing dies, earthenwear-molding dies, conveyor rollers, mill balls, and others. Ni-hard has a martensitic matrix noted for high wear resistance, increased linear shrinkage, up to 2%, and possesses low casting properties, as do white irons.

Nonmagnetic irons. These are high-alloy irons containing such basic alloying components as nickel, manganese, copper, and aluminum. The addition of these elements produces an austenite matrix in the iron. To obtain the austenitic structure in an iron alloyed with nickel and manganese, the approximate carbon content of these components must satisfy the equality [% Ni] + 2.5 [% Mn] + + 1.8 [% Cl] = 33.

Nonmagnetic irons have 9 to 12% Ni; an addition of 2% Cu offers the possibility for decreasing the nickel content.

Since nickel is a critical material, the iron grades with up to 20-30% Al have been developed to substitute for irons high in nickel.

Corrosion-resistant irons. *Low-chromium irons* are highly resistant to attack by sea and tap water. Irons alloyed with 0.5-1% Ni show enhanced stability to alkalis. Irons alloyed with chromium and nickel (a 0.5 to 1% content of each) are still more resistant to the attack of alkalis. Irons containing 0.8% copper and 0.8% antimony have 20 to 30 times the resistance of plain irons to the corrosive effect of hydrochloric acid.

Ferrosilicides hold a particular place among corrosion-resistant alloys. These alloys contain 14.5-18% Si and about 0.5% C.

High-silicon irons of the ferrosilicide type are rather fluid, resistant to wear, brittle, and poorly machinable. The linear shrinkage is high, 1.7 to 2.3%, and the Brinell hardness is 2 740 to 4 500 MPa (300 to 460 kgf mm⁻²). These alloys resist the attack of hydrochloric acid diluted to any concentration. A high chemical stability of the alloys in question is due to a protective silica film produced on the surface of a casting under the action of acids. Hot hydrochloric acid and some other substances destroy the silica film that protects the alloys from corrosion. Yet silicon-molybdenum irons are resistant even to the above substances; they usually have an increased content of molybdenum, up to 3.5-4%.

Austenitic irons show high corrosion resistance. An example is ni-resist which is highly stable at common temperature to hydrochloric, formic, and acetic acids, to caustic soda and some salts and alkalis, and also sea water. The composition of ni-resist includes 0.4% P, about 0.12% S, 12-16% Ni, 6-8% Cu, and 1.5-4% Cr. These irons exhibit good wear resistance and temperature stability. They are used for I.C.E. cylinders and cylinder sleeves.

High-temperature irons are used for castings intended to operate at about 600°C under dynamic load. The additives that impart high-temperature strength to the irons include nickel, chromium, and molybdenum. These irons must have an austenite-carbide structure, with graphite present in nodular form. Castings are heat treated; the stages involved in the process include heating to 1 030-1 050°C, holding for 2-4 hours, normalizing, and then tempering at 550-620°C.

Heat-resistant irons are capable of resisting volume changes ($\leq 2\%$) and scaling [$\leq 0.5 \text{ g}/(\text{m}^2\text{h})$] at a specified temperature for 150 hours. Iron castings employed for high-temperature service break down not only for the mere reason that they are insufficiently heat resisting, but also as a result of volume changes (thermal growth) which occur at a temperature above 400°C and can reach 10%. Where this is the case, the iron castings warp, develop cracks and fail to operate at all. Thermal growth results from the fact that cementite present in iron disintegrates under heat to liberate graphite which grows in volume by about 2.5% because hot gases penetrate into graphite cavities and oxidize the iron. The larger the clusters of graphite separated out from the iron during decomposition of cementite, the more intensive is the penetration of gases into the iron and the more vigorous is its oxidation.

In order for iron castings to be more heat resistant and stable to thermal growth, the chemical composition of an iron must promote the formation of a durable protective skin on castings to keep gases from penetrating into the metal and preclude decomposition of cementite.

A high-silicon cast iron with 5% Al, known as silal, has low strength and toughness and is subject to cracking. The alloying additions of manganese or chromium improve its mechanical properties; copper additions increase its resistance to scaling and make it more fluid. A silal variety with nodular graphite features high resistance to scaling and thermal growth.

An aluminum cast iron with 19 to 25% Al, known by the Soviet trade-name chugal, is highly resistant, easily machinable and has comparatively good casting properties. It shrinks strongly; the volume of shrinkage voids is 3 to 7% for the iron grade with 18 to 23% Al. The linear shrinkage is 2.4 to 2.6% for the iron grade with 25% Al. The nodular graphite aluminum cast iron is superior in heat resistance to the flake graphite gray cast iron. The aluminum cast iron is used for the production of crucibles to melt aluminum alloys.

Chapter 2. CHARGE MATERIALS. CHARGE CALCULATION

2.1. METAL CHARGE

The basic materials that enter the composition of metal charge in melting cast iron are **pig iron** from the blast furnace, iron and steel scrap, briquetted iron and steel chips, and foundry returns comprising gates and risers cut off from castings, various scrap, and rejected castings. Ferroalloys such as ferrosilicium, silicocalcium, ferromanganese, and others serve as additions made in the charge in quantities such as required for melting a particular grade of iron.

2.1.1. PIG IRON

By the purpose they have to serve, irons produced in blast furnaces with the use of coke are divided into *foundry pig iron* and *conversion pig iron*.

Foundry pig iron is in turn classified into general-purpose and special types. Special grades are used for castings of mill rolls, for malleable iron castings, and other castings with chilled surface. Iron smelted in blast furnaces from the ore containing alloying elements is known as natural alloy pig iron. Coke pig iron comes in seven grades according to composition (Table 39). Irons of each grade are subdivided into groups (by the amount of phosphorus), and into categories (by the amount of sulfur).

Special foundry pig iron finds application where plain pig iron proves unsuitable for castings which must have a strictly definite

Table 39
Composition of Coke Pig Iron, %

Grade	C	Si	Mn			P	
			Group			Class	
			I	II	III	A	B
ЛК1	3.5-4.0	3.21-3.6					
ЛК2	3.6-4.1	2.81-3.2					
ЛК3	3.7-4.2	2.41-2.8					
ЛК4	3.8-4.3	2.01-2.4					
ЛК5	3.9-4.4	1.61-2.0					
ЛК6	4.0-4.5	1.21-1.6					
ЛК7	4.1-4.6	0.81-1.2					
			≤ 0.05	0.51-0.9	0.91-1.5	≤ 0.08	0.081-0.12

Table 39 (cont.)

Grade	C	Si	P			S, not over				
			Class			Category				
			В	Г	Д	1	2	3	4	5
ЛК1	3.5-4.0	3.21-3.6								—
ЛК2	3.6-4.1	2.81-3.2								
ЛК3	3.7-4.2	2.41-2.8								
ЛК4	3.8-4.3	2.01-2.4	0.13-0.7	0.71-1.2	0.31-0.7	0.02	0.03	0.04	0.05	—
ЛК5	3.9-4.4	1.61-2.0								0.06
ЛК6	4.0-4.5	1.21-1.6								0.06
ЛК7	4.1-4.6	0.81-1.2								0.06

amount of silicon, manganese or phosphorus. The uses include malleable iron castings, castings of mill rolls, and others. The iron is available in nine grades which differ in the composition and the purpose each being assigned to serve (Table 40).

Table 40

Composition of Special Foundry Pig Iron, %

Grade	Si	Mn	P	S	Cr	Application
			not over			
КК	1.00-1.50	0.20-0.60	0.10	0.03	0.04	For malleable iron castings (coke pig iron)
КД1	0.71-1.50	0.1-0.40	0.15	0.03	0.04	For malleable iron castings (charcoal pig iron)
КД2	0.15-0.70	0.10-0.30	0.15	0.03	0.04	
ВК1	0.50-1.00	0.20-0.60	0.40	0.03	0.04	For rolls of rolling mills (coke pig iron)
ВК2	0.10-0.50					
ВД1	0.81-1.30	0.20-0.80	0.40	0.06	0.04	For rolls of rolling mills (charcoal pig iron)
ВД2	0.30-0.80					
ЧК	0.50-1.00	0.50-1.00	0.20-0.35	0.07	0.10	For wheels with chill rims
ЛКА	2.76-3.75	0.50-0.90	0.60-0.90	0.25	—	For aircraft industry

Notes: 1. Total carbon content of iron grade ЧК must be under 4.2%, and iron grade ЛКА 3.5 to 3.8%.

2. Copper content of iron grade ЧК must be under 0.3%.

Conversion pig iron comes in five grades (Table 41).

Table 41
Composition of Conversion Coke Pig Iron, %

Grade	Si	Mn			P			S, not over			
		Group			Class			Category			
		I	II	III	A	B	B	I	II	III	IV
M1	0.91-1.30	≤ 0.50	0.51-1.0	1.01-1.50	0.15	0.20	0.30	0.02	0.03	0.04	0.06
M2	0.51-0.90										
M3	≤ 0.50										
E1	0.91-1.4		0.3-0.70		0.06	0.07	—	—	—	0.4	—
E2	≤ 0.9				0.06	0.07	—	—	—	0.04	0.06

- Notes:* 1. It is permissible to use iron grade M2 of all groups, classes, and categories (exclusive of category IV) for conversion in oxygen-converter plants.
 2. It is permissible to produce iron grades M1, M2, and M3 with a copper content below 0.3%.

Natural alloy pig iron (Table 42) is added to the charge to increase the strength and wear resistance of castings. For alloying of iron castings, it is advisable to add 8 to 12% chromium-nickel iron to the charge, though this makes the charge a little costlier.

Table 42
Composition of Natural Alloy Pig Irons, %

Grade	Si	Mn	Ni + Co	Cr	Application
ЛХЧ1 МХЧ2	≥ 2.76 2.26-2.75	0.61-1.2 1.20	≥ 1.0	2.20-2.70	For cylinder blocks, sleeves and other parts used in machine building
ЛХЧ3	1.76-2.26	≤ 0.6	≥ 1.0	2.71-3.20	For hardened castings
ЛХЧ4 ЛХЧ6	1.26-1.75 On order	≤ 0.60 ≤ 1.20	≥ 1.0 ≥ 0.80	2.71-3.20 ≥ 3.0	For heat-resisting castings

Titanium-copper alloy iron is used for antifriction castings and particularly for individual castings of piston rings, cylinders, household refrigerator parts, and so on. Foundry pig iron alloyed with titanium and copper is available in three grades (Table 43).

Table 43
Composition of Titanium-Copper Alloy Iron, %

Grade	Si	Mn	P	S	Cu	Ti
БТМЛ3	1.75 and over			0.03		
БТМЛ4	1.26-1.75	0.4-1.0	≤ 0.50	0.04	2.0	0.60-1.20
БТМЛ5	0.75-1.25			0.04		

Note: The content of nickel is not limited; the content of chromium is up to 0.05%.

2.1.2. FERROALLOYS AND INOCULANTS

Pig ferroalloys. Specular (spiegel) iron finds use as an alloy addition in the production of cast iron in the cupola. Ferromanganese (Table 44) serves the same purpose and also as a dioxidizer of steel

Table 44
Composition of Pig Ferroalloys, %

Ferroalloy	Grade	Si	Mn	P	S	C
			not over	approximately		
Spiegel	341	2	20.1-25.0	0.22	0.03	—
	342		15.1-20.0	0.20		
	343		10.0-15.0	0.18		
	Mn5	2	> 75.1	0.35	0.03	6.0
	Mn6		70.0-75.0	(group A) 0.45 (group B)		5.5-6.5

and as an inoculant.

Electrothermic ferroalloys (from the electrothermic furnace). These are deoxidizers of steel and inoculants of cast iron. Ferrous alloys such as ferrochromium, ferrotungsten, ferromolybdenum, and ferrotitanium are used as alloy additions in the manufacture of steel

and cast iron. Ferrophosphorus serves as a charge addition in melting cast iron rich in phosphorus (for the manufacture of iron dishware and art castings). Phosphorus is added to malleable iron to increase fluidity, and to nonferrous alloys to deoxidize copper. Ferrophosphorus contains about 1.2% C, 2.2% Si, 6% Mn, 14-18% P, 0.5% S, the balance being iron.

Table 45
Composition of Ferrosilicon, %

Grade	Si	C	S	P	Al	Mn	Cr
		not over					
ΦC 90	≥89	—	0.02	0.03	3.0	0.2	0.2
ΦC 75 φ	74-80	0.1	0.02	0.03	1.3	0.3	0.2
ΦC 75	74-80	—	0.03	0.05	2.5	0.4	0.4
ΦC 65	63-68	—	0.03	0.05	2.0	0.4	0.4
ΦC 45	41-47	—	0.03	0.05	2.0	0.6	0.5
ΦC 25	22-29	0.6	0.03	0.06	1.0	0.9	—
ΦC 18	17-22	1.3	0.04	0.10	1.0	1.0	—

Ferrosilicon (Table 45), aluminum, calcium silicon, and magnesium are deoxidizers of steel and inoculants of iron. Calcium silicon is available in several grades with a calcium content ranging from 10-15% to 25-30% and above.

Inoculation of iron with magnesium is effected by using a master alloy containing 61% Si, about 30% Fe, 5% Mg, about 2% Al, 1.7% Ca, and 0.3 P. In use are also such inoculants as cerium, ferrocerium (15% Fe, 40-55% Ce, the balance rare-earth elements), and an alloy of rare-earth elements with magnesium. This alloy consists of 40-50% Ce, about 1% Fe, 3.6-7.5% Mg, and elements of the ceric group. Other inoculants sometimes employed in the production of cast iron are boron, ferroboron (4-7% B), aluminum, and bismuth.

2.1.3. IRON SCRAP AND FOUNDRY RETURNS

Along with pig iron purchased from metallurgical works, the metal charge to a cupola must contain iron and steel scrap and foundry returns—gates, risers, metal scrap, castings, chips, rejected castings and other metal rejects.

Iron scrap and foundry returns added to the charge speed up the process of melting and enable better overheating of the iron. The pieces of scrap metal must measure not over 250 × 200 × 100 mm and weigh from 1 to 35 kg. Large-sized scrap are fragmented by

a drop hammer. Steel scrap is cropped by arc or torch cutting. It should be kept in mind that adequate shredding raises the cupola output and increases the temperature of the metal being tapped. Scrap and foundry rejects should be cleaned from sand, scale, and dirt.

Purchased scrap must be forwarded with a certificate evidencing its chemical composition. Iron scrap and other types of waste must be free of alloying admixtures; for malleable iron castings, for example, a content of chromium over 0.05 or 0.06% is inadmissible since, otherwise, the iron will not lend itself to annealing.

The cupola charge should contain 40 to 50% steel scrap if it is necessary to reduce the carbon content of the iron. To steel scrap belong shearings of plate and section iron, rails, steel parts, press forging waste, and others. Pieces of steel scrap must be cut to the same size as iron scrap pieces. Cuttings and swarf are charged into the cupola in the form of briquettes which must be strong enough to stand handling, that is, not to fall into pieces during loading.

Prior to briquetting, chips should be cleared of dirt, oil, and rust.

Every carload of metal charge delivered to the foundry must be inspected for acceptance and stored separately. Pigs for small-diameter cupolas are crushed by pig breakers. It is permissible to charge as-cast pigs into a cupola over 2 m in diameter. In all cases the length of metal pieces must be about one-third the inside diameter of the cupola, otherwise they will hang up (causing what is called bridging, or scaffolding). The averaged composition of cupola charge is given in Table 46.

Table 46
Averaged Composition of Cupola Charge, %

Iron of castings	Pig iron	Purchased scrap		Foundry rejects	Ferro-alloys
		Iron	steel		
Nodular graphite	30-50	20-30	0-10	30-35	1-2
Flake graphite	20-40	15-25	10-20	30-35	2-3
Malleable	10-20	10-20	30-50	35-45	2-4

2.2. FUELS

The basic fuels used for melting iron in the cupola are coke and, sometimes, natural gas. The quality of coke varies with the size of lumps, their density, reactivity, mechanical strength, and the content of ash and sulfur. The choice of the size of coke lumps depends on the cupola's inside diameter.

Table 47
Classification and Properties of Foundry Fuel

Kind and grade	Content, %				Lump size, mm
	Sulfur under	Ash	Moisture	Volatile	
Coal coke:					
KJL-1	0.6	12.0			
KJL-2	1.0	11.0			
KJL-3	1.4	12.0			
Anthracite:					
1st kind	1.2	6.5	2.0	0.7	40-120
2nd kind	1.75	6.5	2.0	0.7	40-120
Pitch coke	0.8-1.3	4.0-8.0	3.0	3.0	≥ 40

Note: All coke grades are broken down into classes according to the size

Cupola's inside diameter, mm	Coke lump size, mm
< 900	65-90
900-1 000	65-140
1 000-1 200	90-140
1 200-1 500	120-140
> 1 500	> 140

The fuel should contain no more than 8-10% ash. In the cupola, the coke bed and the coke split have to bear up a heavy column of metal charge. That is why the coke lumps must be strong enough to withstand heavy load. If the coke is insufficiently strong it breaks up into small pieces and thus does not allow uniform distribution of the blast throughout the shaft and proper overheating of the metal. Coke should be tested for strength and screened to remove dust because the coke fines together with slag promote the formation of skull (slag and metal buildup) in the tuyere zone. This also leads to an increased consumption of coke. Coke is tested in a rotary drum 2 m in diameter and 0.8 m in length, made up of iron bars spaced 25 mm apart. The drum is loaded with a batch of coke 410 kg in mass and made to rotate for 15 min at a speed of 10 rpm. The coke breaks up and small pieces drop out of the drum. The remaining coke is weighed to determine the so-called tumbler test sample. The mechanical strength of coke after the drum test must be not less than 300-325 kg. The moisture content must be at a minimum, about 2-4%. The lower the fuel reactivity (the ability of coke to reduce CO₂

Fines, %, under	Porosity, %	Calorific value, kcal/kg	Volume mass, kg/m ³	Coke left in drum, kg	Strength, % up to
4	≤ 42	6 500-7 000	450-500	—	75
5	2-5 } 5 2-5 }	6 800-7 300	850-950	— —	55 55
4	25-35	7 500-8 000	500-550	300	—

of lumps: > 80, > 60, > 40, 60-80, and 40-60 mm.

to CO at 900°C), the higher the ratio CO₂/CO for the combustion gases and the hotter the run of the furnace. The sulfur content of various grades of cupola coke must not exceed 0.6-1.4%. Coke must exhibit the lowest tendency to fracturing.

Foundry (cupola) coke differs from blast furnace (metallurgical) coke in that it has a higher density and strength, lower reactivity, and smaller percentage of ash (ash content). Foundry coke is available in three grades (Table 47). Coke of the KJ-1 grade has the lowest ash content (below 0.6%) and the KJ-3 grade the highest ash content (1.4%). The KJ-3 grade surpasses the KJ-2 grade and still more so the KJ-4 grade in strength, size of lumps, and porosity.

Thermoanthracite is noted for a low reactivity and high calorific value. It does not break up as readily as does anthracite during the cupola run. Thermoanthracite has a lower reactivity than coke, but higher than anthracite.

Pitch coke (see Table 47) is a synthetic fuel, a substitute for native coke. It has low porosity (20 to 25%) and reactivity, small content of sulfur, high strength and calorific value.

2.3. FLUXES

Fluxes are mineral substances added to the charge to reduce the temperature of slag melting, to obtain a slag of required viscosity and fluidity, and to remove ash from the fuel that gets into the slag.

Foundry fluxes used for melting iron in the cupola include limestone, open-hearth slag, fluorspar (fluorite), and apatite-nepheline ore.

Limestone must contain 40 to 50% CaO, about 1% Si, and a minimum amount of sulfur and phosphorus. It is possible to assess the quality of limestone without resorting to complete chemical analysis. For this we must know just how much insoluble residue it contains. An averaged test sample of limestone 0.5 g in mass is ground and dissolved in a test tube with 6.5 cm³ hydrochloric acid (taken in the proportion 1 to 1). The powder dissolves for 20 to 30 s. By the amount of residue in the tube, we can determine the kind of limestone (Table 48).

Table 48

Limestone Composition, %

Kind	CaO, up to	SiO ₂	Insoluble residue	Al ₂ O ₃ + + Fe ₂ O ₃	MgO	P ₂ O ₅	O ₂
I	52	1.75	2.15	2	3.5	0.02	0.25
II	50	3.0	3.75	3	3.5	0.04	0.35
III	49	4.0	5.0	3	3.5	0.05	0.35

Limestone must be broken up in a stone crusher into pieces 25 to 100 mm in size because larger lumps melt with difficulty, while smaller pieces are carried away by combustion gases; this is particularly the case if the cupola runs at a high blast pressure.

Open-hearth slag. For iron melting, cupolas use basic open-hearth slag from basic electric furnaces. This slag is lusterless in fracture, dense, and has the following composition: under 25% SiO₂, 40% CaO and MgO, over 20% FeO and MnO, and near 2% P₂O₅, and 4% CaS. The content of iron oxides must not exceed 10%. The open-hearth slag used in a cupola must be crushed to pieces 25-100 mm in size. The amount of this slag charged into the furnace may range from 0.5 to 1.2% of the mass of metal charge.

Fluorspar lowers the viscosity and melting point of slag and thus speeds up chemical reactions occurring in the slag, raises the solubility of iron and partially combines with sulfur. Fluorspar high in SiO₂ heavily reduces the viscosity of slag.

Fluorspar is divided into three varieties, or kinds. Fluorspar of the 1st kind must contain over 92% CaF₂ and about 5% SiO₂; the 2nd kind, over 82% CaF₂ and about 20% SiO₂; and the 3d kind, about 25% CaF₂, with no limits being set on the content of SiO₂. For melting iron in a basic cupola, the additions of fluorspar may reach 8% of the charge. Fluorspar is a scarce mineral. It strongly attacks cupola lining, therefore the fluorspar content should not commonly exceed 1.5-2% of the mass of fuel bed.

Apatite-nepheline ore is a mineral of the composition $3\text{Ca}_3\text{PO}_4 \cdot 2\text{CaF}_2$. The ore is available in three kinds. The 1st kind contains 25 or 26% P_2O_5 , the 2nd, 28 or 29% P_2O_5 , and the 3d kind 31 or 32% P_2O_5 ; 1 kg of ore has as much as 0.13-0.14 kg phosphorus. For melting cast iron in a cupola, the second kind of ore should be preferred. The ore is crushed to lumps 25 to 100 mm in size. The 2nd kind of ore is sometimes used as a substitute for limestone (1% ore against 0.5% limestone) or as a phosphotizing agent added to iron (in particular, malleable iron) to increase its fluidity.

2.4. CHARGE CALCULATION

The composition of iron for various castings. The choice of iron composition depends on the purpose of castings, casting wall thickness, and the contents of silicon and carbon in the iron. Table 49

Table 49

Carbon Content of Iron Versus Casting Wall Thickness

Wall thickness, mm	Carbon content, % in casting iron				Wall thickness, mm	Carbon content, % in casting iron				
	into sand molds		into permanent molds			into sand molds		into permanent molds		
	with cores	without cores	with cores	without cores		with cores	without cores	with cores	without cores	
6-10	2.2-2.6	3.0-3.3	2.8-3.0		21-40	1.6-2.0	2.6-2.8	2.2-2.4		
11-20	1.8-2.2	2.8-3.0	2.4-2.7		41-80	1.5-1.8	2.4-2.6	2.0-2.4		

gives an approximate silicon content of iron as a function of the casting wall thickness. In each concrete case, the silicon content has to be specified with due regard to the conditions and nature of production, and the quality of initial materials available.

Charge calculation methods. To ensure the specified chemical composition and quality of iron being melted, we should calculate the charge according to the accepted chemical composition of liquid iron taking into account the loss of metal which occurs during melting.

The charge is calculated per 100 kg of the metal batch (a metal charge introduced into a furnace at a time). The mass of the metal charge for the given program of melting is a sum total of the masses of the following components: (1) sound castings required according to the program drawn up for a month, a quarter, a year, a day, or per heat; (2) castings rejected in the foundry and in mechanical shops; (3) gates, flowoffs, and risers; (4) melting loss and mechanical

loss incurred during tapping and pouring (overflows, splashes, spatters, and so forth).

The mass of gates varies in the range from 20 to 80% for small castings, 15 to 25% for medium-size castings, and 5 to 15% for large castings.

The loss of metal in a cupola may be taken to be equal to 4 or 5% of the total mass of the metal charge. For reverberatory furnaces, the percentage is higher, 6 to 8%.

The casting yield (in percent) is the ratio between the net mass of sound castings and the mass of the metal charge:

$$\text{Casting yield} = \frac{\text{net mass of sound castings}}{\text{mass of metal charge}} \times 100\%$$

The casting yield for small gray iron castings ranges from 40 to 60%, for medium-size castings 55 to 70%, and for large castings 65 to 80%; for malleable iron castings, the casting yield is 55 to 62%. The loss of charge elements due to burning in the cupola is as follows: 10 to 30% Si, 15 to 25% Mn, and 16 to 20% Cr. The pickup of sulfur as it passes from coke to iron averages 40 to 50%.

The loss of additions in the iron depends on the absolute content of the additions made to the charge and types of furnace employed (hot-blast, cold-blast, coke-gas, and others). The charge may be calculated by a trial-and-error method, analytical method, and graphical method. The first method enjoys most extensive applications since it is the simplest.

An example of charge calculation by a trial-and-error method. The gray iron used for casting automotive parts must have the following composition: 3.2-3.4% C, 2.0-2.2% Si, 0.6-0.8% Mn, about 0.15% P and 0.12% S. The melting loss in the cupola is 15% Si and 20% Mn; the pickup of sulfur comes to 50%. The chemical composition of charge materials is given in Table 50. The mass of metal charge is 800 kg.

Table 50

Composition of Charge Components, %

Component	C	Si	Mn	P	S
Pig iron:					
JIK1	3.5	3.3	0.50	0.11	0.02
JIK2	3.6	3.0	0.50	0.12	0.03
Foundry returns	3.3	2.1	0.70	0.10	0.09
Steel scrap	0.2	0.3	0.80	0.05	0.05
Briquetted iron chips	3.3	2.1	0.70	0.10	0.09

Determine the mean contents of silicon and manganese in the charge. Assume the sought-for content of silicon in the charge is x (%), that of manganese y (%), the silicon loss $0.15x$, and the manganese loss $0.20y$. The amount of silicon left in

the molten metal is $x - 0.15x = 0.85x$ and that of manganese, $y - 0.20y = 0.80y$.

In conformity with the specified composition of the iron, the mean contents of silicon and manganese left in the liquid metal must be 2.1% and 0.7% respectively. Thus,

$$x = \frac{2.1\text{Si}}{0.85} = 2.47\%, \quad y = \frac{0.7\text{Mn}}{0.8} = 0.87\%$$

Calculate the charge composition, that is determine the percentages of components which make up the charge. In accordance with the assigned task (see Table 50), the charge must comprise five kinds of metal. Based on the available charge materials and knowing the chemical composition of each, we select the appropriate mass of individual components of the charge and then check by calculation the percentages of elements which constitute the charge (Table 51).

From Table 51 it is seen that the carbon content of the iron to be melted lies within the preset limits, while the silicon content falls 0.46% short of meeting the demand for one heat: $2.47\% - 2.01\% = 0.46\%$, or $(0.46 \times 800)/100 = 3.68$ kg. The charge will also be deficient in manganese: $0.87\% - 0.63\% = 0.24\%$ or $(0.24 \times 800)/100 = 1.92$ kg per heat. An addition of ferrosilicon can make up for the shortage of silicon (1 kg ferrosilicon contains 0.09-0.13 kg silicon). The melting loss of silicon and ferrosilicon will total some 25%; that is 1 kg of ferrosilicon gives 0.07-0.09 kg of silicon that will pass into the casting. So, the metal charge (800 kg) must contain not less than $(1 \times 3.68)/0.07 = 52.57$ kg of ferrosilicon or $52.57/8 = 6.57$ kg of ferrosilicon for every 100 kg of charge.

We add ferromanganese to compensate for the deficiency in manganese (1 kg of ferromanganese may contain 0.7-0.75 kg manganese). The melting loss of manganese averages 30%. Thus, we have to add $1.92/0.7 = 2.7$ kg of ferromanganese to the metal charge (800 kg) or $2.7/8 = 0.33$ kg per 100 kg of the charge.

From the calculations we can now write the composition of the metal charge 800 kg in mass:

Pig iron:	Content, kg
I K1	200
II K2	120
Foundry returns	240
Steel scrap	120
Briquetted iron chips	120
	Total 800

The required amount of fuel depends on the method of melting the cast iron in the cupola. It generally accounts for 9 to 16% of the mass of metal charge. For example, a cold-blast cupola consumes about 15% coke of the mass of charge, a hot-run cupola 11%, and a coke-gas hot-blast cupola 9%. Fluxes constitute 3% of the mass of metal charge.

It is advisable to calculate a charge by the trial-and-error method if the constituents of its composition remain invariable day after day, that is, if it consists of the metals of the same grades. In blending new charges, the required calculations should be performed with the aid of an analytical method.

An example of charge calculation by an analytical method. The method consists in setting up the system of equations in which the unknown variables are

Table 51
Calculation of the Contents of Elements in the Charge

Component	Mass			Element content			
	kg	%	C	Si	Mn	P	S
Pig iron	200	25	0.25×3.5 = 0.875	0.25×3.3 = 0.825	0.25×0.5 = 0.125	0.25×0.11 = 0.027 5	$0.25 \times 0.02 = 0.005$
		120	15	0.15×3.6 = 0.540	0.15×3.3 = 0.495	0.15×0.5 = 0.075	0.15×0.12 = 0.018
Foundry returns	240	30	0.30×3.3 = 0.990	0.3×2.4 = 0.630	0.3×0.7 = 0.210	0.30×0.10 = 0.03	$0.30 \times 0.09 = 0.027$
		120	15	0.15×3.3 = 0.495	0.15×0.1 = 0.015	0.15×0.7 = 0.105	0.15×0.10 = 0.015
Briquetted chips							$0.15 \times 0.09 = 0.013 5$
Steel scrap	120	15	0.15×0.20 = 0.03	0.15×0.30 = 0.045	0.15×0.8 = 0.120	0.15×0.05 = 0.0075	$0.15 \times 0.05 = 0.007 5$
Total	800	100	2.93	2.01	0.635	0.098	$0.057 5 + 0.028 7* = 0.086 2**$

* Pickup of sulfur from coke is 5.0%.

** Sulfur content of iron to be melted will be below the specified value.

the contents of elements in the charge and in the iron. To simplify the calculation, it is usual to set reasonable values of two or three unknowns.

Assume the castings should contain 1.9% Si and 0.65% Mn. Let the loss of silicon and of manganese in the cupola be 10% and 20% respectively. Then, taking into account the melting loss, we can calculate the percentages of silicon and manganese to be introduced into the charge:

$$\text{Si} = \frac{1.9 \times 100}{100 - 10} = \frac{190}{90} = 2.1\%$$

$$\text{Mn} = \frac{0.65 \times 100}{100 - 20} = \frac{65}{80} = 0.8\%$$

We take it that the charge can be proportioned from the four kinds of metal, whose chemical composition (as regards the content of silicon and manganese) is given in Table 52. The foundry returns make up 40% of the metal charge, the balance (60%) being pig iron of three grades.

To make certain that the charge can be prepared from the components listed in Table 52, we should first find out whether a possibility exists for obtaining

Table 52

Composition of the Charge, %

Component	Content, %	Si	Mn
Pig cast iron:			
A	x	2.1	0.9
B	y	2.3	0.95
C	z	2.2	0.8
Foundry returns	40	2.0	0.7

the desired contents of silicon and manganese.

The averaged pig iron silicon content is

$$\text{Si} = \frac{2.1 + 2.3 + 2.2}{3} = 2.2\%$$

The silicon content of scrap is 8%. Thus, the mean content of silicon per 100 kg of charge is

$$\text{Si} = \frac{60 \times 2.2}{100} + \frac{40 \times 2}{100} = 2.1 \text{ kg}$$

Determine the manganese content in the same manner:

$$\text{Mn} = \frac{60}{100} \left(\frac{0.9 + 0.95 + 0.8}{3} \right) + \frac{40}{100} \times 0.7 = 0.81 \text{ kg}$$

To find the values of unknown quantities x , y , and z , we set up three equations, assuming that the mass of the charge is equal to 100 kg. In this case, the percentage of each component will be equal to the mass of each component in kilograms.

The first equation

$$x + y + z + 40 = 100, \text{ or } x + y + z = 100 - 40 = 60$$

The second equation for silicon

$$2.1x + 2.3y + 2.2z + 40 \times 2.0 = 100 \times 2.1, \text{ or}$$

$$2.1x + 2.3y + 2.2z = 210 - 80 = 130$$

The third equation for manganese

$$0.9x + 0.95y + 0.8z + 40 \times 0.7 = 100 \times 0.8, \text{ or}$$

$$0.9x + 0.95y + 0.8z = 80 - 28 = 52$$

Expressing x through y and z and performing the requisite transformations, we obtain two equations with two unknowns:

$$0.2y + 0.1z = 4 \text{ and } 0.05y - 0.1z = -2$$

Summing up the two equations, we find y :

$$0.25y = 2.0, \text{ whence } y = 8$$

Substituting the value of y into one of the equations, we obtain $z = 24$. The value of x may be found from the equation $x + 8 + 24 = 60$; whence $x = 28$.

We can now write the content of each component per 100 kg of the metal charge:

Pig iron grades:	Content, kg
A	28
B	8
C	24
Foundry returns	40
	Total 100

A graphical method of charge calculation. Consider the simplest case of charge calculation for evaluating the content of silicon in the two constituents, iron scrap A and pig iron B. Denote the silicon content of the charge by a (%), that of iron scrap by a_1 (%), and that of pig iron by a_2 (%). Let the sought-for quantity of iron scrap A and of pig iron B in the charge be x (%) and y (%) respectively.

First we set up the balance equation

$$x + y = 100$$

The quantity of silicon introduced into the charge with iron scrap A may be expressed as $a_1x/100$ (%), and with pig iron B as $a_2y/100$ (%).

The quantity of silicon in the charge will be found from the equation

$$\frac{a_1x}{100} + \frac{a_2y}{100} = a, \quad \text{or } a_1x + a_2y = 100a$$

So, for calculating the charge to be blended from the two components we have the system of linear equations with two unknowns x and y :

$$x + y = 100, \quad a_1x + a_2y = 100a$$

Solving these equations, we obtain

$$x = 100 \frac{a_2 - a}{a_2 - a_1} \quad (20)$$

$$y = 100 \frac{a - a_1}{a_2 - a_1} \quad (21)$$

This system of equations may be solved graphically.

If the coordinates of points $A (a_1)$ and $B (a_2)$ on the straight line (Fig. 157a) correspond to the contents of silicon in the starting

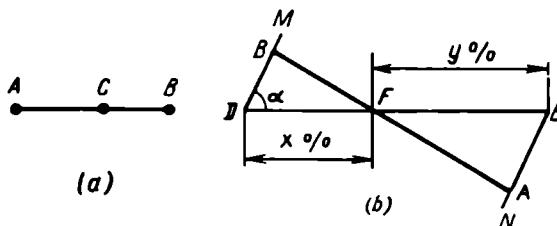


Fig. 157. Calculating a two-component charge by the graphical method

charge materials, then between these two points we will be able to lay off the points characteristic for the possible variants of the composition of the charge from scrap A and iron B. A certain point C represents such a variant. If the point C lay outside the line AB, this would indicate that it is impossible to blend the charge from the components in question.

From analytical geometry we know that, whatever the location of points, the distance from the first point to the second is equal to the difference between the coordinates of the beginning and end of the segment: in other words $AC = a - a_1$ and $BC = a_2 - a$. From formulas (20) and (21) it follows that

$$\frac{x}{y} = \frac{a_2 - a}{a - a_1} \quad \text{or} \quad \frac{x}{y} = \frac{BC}{AC}$$

Thus, the point C that corresponds to the composition of the charge being calculated (for the content of silicon) divides the segment (between the charge components) into portions which quantitatively are in inverse proportion to the contents of the charge constituents.

To calculate the mass of each charge constituent, take a segment DE (Fig. 157b) and mark a linear scale on it to have the scale ranging from 0% (at D) to 100% (at E). Draw through the point D a straight line DM at a slant to DE , for example, at an arbitrary angle α (usually at 40 to 80°). Next draw through the point E a straight line EN parallel to the line DM . If we lay off a segment DB equal to BC (see Fig. 157a) on the line DM and a segment $EA = AC$ on

the line EN and connect the point A with the point B by the line, then the point of intersection, F , of this line with the line DE will indicate the percentages of the charge components. Quantitatively, the segment DF corresponds to the mass x of iron scrap A and the segment FE to the mass y of pig iron B. The triangle BDF is similar to the triangle AEF . From the similarity of triangles, we may write

$$\frac{DB}{EA} = \frac{DF}{EF}$$

Since $DB = BC$ and $EA = AC$, then according to the equation

$$\frac{x}{y} = \frac{BC}{AC}, \quad \frac{x}{y} > \frac{DF}{EF}$$

An example of charge calculation by the graphical method. We have to make up the charge for the production of cast iron in the cupola of the following composition: 3.4% C, 2.1% Si, 0.55% Mn, 0.7% P, and about 0.1% S. The charging materials available at the store are pig iron with 3% Si, 0.8% Mn, and 0.03% S and machinery scrap with 1.9% Si, 0.5% Mn, 0.1% S, and 0.6% P.

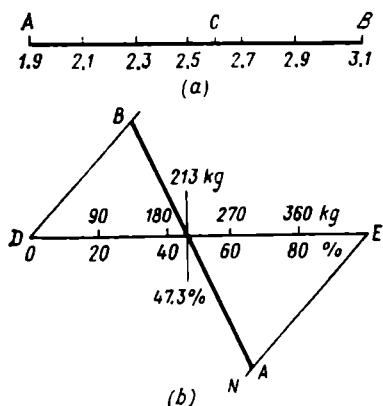


Fig. 158. Example of graphical calculation of the charge

point A by a line, we find that $x = 47.3\%$ and $y = 100 - 47.3 = 52.7\%$, or $x = 213$ kg and $y = 450 - 213 = 237$ kg.

We can determine the content of other elements in the charge in a similar manner. If recalculations reveal a disagreement between the calculated and the required contents of elements in the charge, then the charge composition should be corrected with respect to manganese and sulfur by selecting the pig iron of other grades. Should the iron of selected grades do not secure the preset chemical composition of cast iron, ferroalloys may prove suitable for the purpose.

Chapter 3. MELTING CAST IRON IN THE CUPOLA

3.1. GENERAL

The foundry furnaces used for melting cast iron include cupolas, reverberatory and electric furnaces. It is essential that melting furnaces should produce metal of the required chemical composition at a minimum of melting loss and low fuel rate, secure the desired temperature and the lowest saturation of metal with harmful admixtures and gases.

Foundry furnaces must be tailored for the operating conditions and the capacity of the foundry shop. Of all the iron melting furnaces, cupolas enjoy widest popularity because they are simple in design and maintenance, are noted for small metal loss, low fuel rate, and high output. The cupola is actually a continuous-running shaft furnace whose output ranges from 500 to 25 000 kg/h molten metal. The furnace permits changing the charge, if necessary, during melting and obtain a cast iron of the desired chemical composition with a temperature of the melt in the spout from 1 400 to 1 450°C.

Construction of the cupola. The furnace consists of a shaft support, chimney with a spark arrester (spark catcher), wind belt (blast box) with tuyeres, and forehearth, or receiver (Fig. 159). The steel shell, or mantle, 9, is lined on the inside with a refractory material, fireclay brick 8. The furnace shaft, or stack, is the working chamber where two main processes take place—fuel burning and iron melting. In the upper part of the shaft there is a charging hole 13 for introducing the charge into the furnace. Starting from the cupola hearth (working bottom) and terminating one meter short of the bottom edge of the charging hole, the shaft is lined with refractory brick 8 laid in two courses up to 250 mm thick; from the brickwork upwards as far as the bottom edge of the charging hole, the shaft is lined with perforated firebrick 10; higher still, the shaft is lined with fireclay brick laid flatwise in one course.

The steel shell is from 6 to 12 mm thick depending on the cupola diameter. To allow for free thermal expansion of the lining, the structural arrangement provides for a shell-to-brickwork gap 25 to 50 mm wide, filled with sand 14. The shaft bears on a bottom plate (base plate) 4, which in turn rests on cupola legs, or columns 3. The fettling hole in the bottom plate is closed with a drop bottom (bottom door) consisting of two folds 1 and 2. The working hole (cleaning, or lighting hole) 5 in the lower part of the furnace serves for ramming sand 15 on the drop bottom (in a layer 100 to 300 mm thick), cleaning out, and lighting up the furnace. The layer of rammed sand

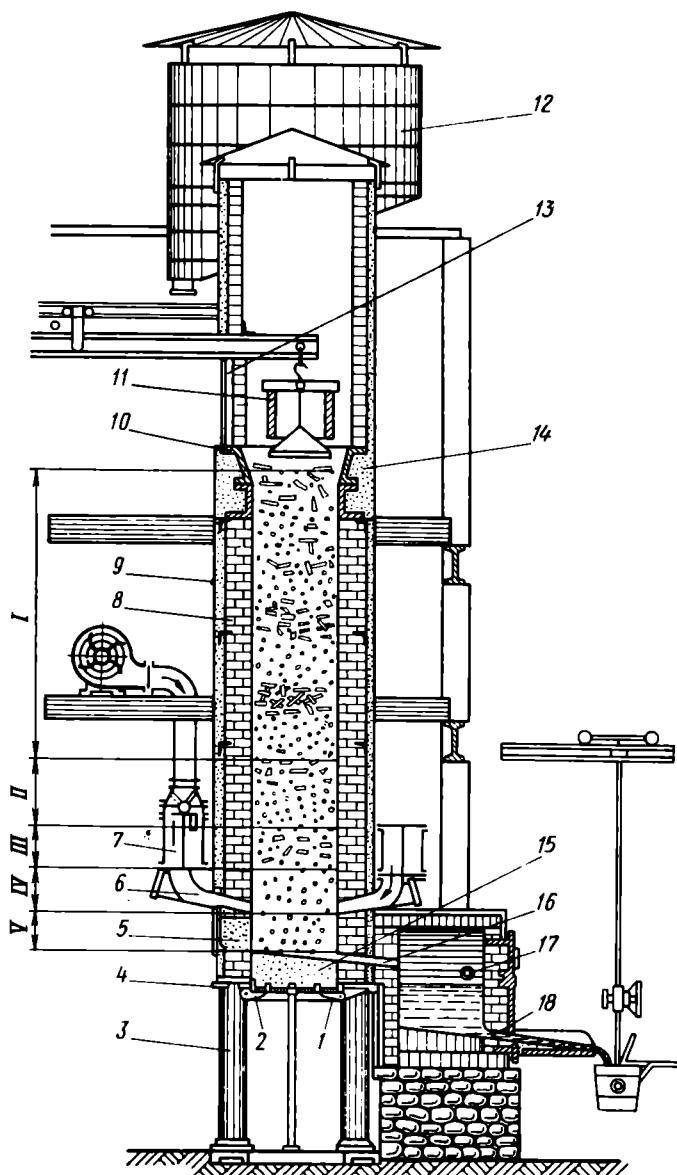


Fig. 159. Receiver cupola

(called cupola hearth) slopes toward an iron taphole 16. The working hole is walled up for the melting period with firebrick, packed with molding sand, and then the door is closed. In the receiver, a slag hole (notch) 17 is located above the metal level. The iron is tapped from the receiver through a taphole 18 into a spout (also known as launder). The shaft with the receiver rests on the basement. The lower part of the shaft from the hearth to the first row of tuyeres is called a cupola crucible, or well.

In operation, the crucible and a certain part of the shaft are filled with glowing coke. This layer of coke is known as the coke bed. A bucket 11 discharges a metal charge in layers on to the coke bed, first pig iron then iron and steel scrap. Next follows a layer of coke, called a coke split, and limestone to be added after forming each coke split. The coke bed 700 to 800 mm in height rises above the tuyere level. An air blower forces the air from a blast box 7 into tuyeres 6. To enable complete combustion of fuel and more intensive melting, the tuyeres are arranged in several rows. The coke bed also serves to keep the level of the melting zone (fusion zone) at a definite height.

The crucible height depends on the cupola diameter and generally ranges from 150 to 300 mm. In cupolas without the receiver the crucible height is determined by the volume of liquid iron required to fill the molds in the tap-to-tap intervals. The crucible height in such cupolas is 400 to 700 mm. The useful height of a cupola is the distance between the lowest row of tuyeres and the bottom edge of the charging hole.

The chimney which serves to carry off the smoke and combustion gases from the shaft terminates in a spark arrester 12 intended to catch hot dust and sparks carried up by the combustion gases and thus to safeguard neighboring premises against fire.

There are spark arrestors of the dry and spray-chamber types. In view of the environment protection requirements, modern cupolas are fitted with gas scrubbers.

The cupola is a furnace of continuous action, which is capable of melting 6 to 10 metal charges for an hour. As the first charge of metal melts down and the height of the charge falls off, new charges are introduced into the furnace.

The molten metal is tapped continuously or at small intervals, 8 to 10 min. The cupola is loaded by a skip charger—a skip hoist loader with inclined guides for conveying drop-bottom buckets 11.

Preparing the cupola for a run. Before starting up the melt, it is necessary to carry out routine repairs to the cupola. The other main types of repair include emergency and capital repairs.

Emergency repairs are done in case of breakdowns (drop of part of the lining during the melt, burnout of the mantle, freezing of the taphole, burnout of the drop bottom, and others).

Capital repairs are major repairs performed one or two times a year after the prolonged furnace campaign. The general overhol may include such operations as repair of the cupola mantle, relining of the shaft, chimney, and spark chamber, and replacement of the blast pipe, wind belt, spark arrester, and also the disabled corner plates which support the lining.

Routine repairs of the cupola are carried out every time the heat is over in order to replace fully or repatch the lining in the melting zone, in the tuyere zone, and in the cupola well. The cupola is cooled after the heat by the natural draft of air, the tuyeres and the bottom door being held open and the charging door closed. Cooling of the cupola lining is intensified by blowing air through the shaft. The materials left intact after the heat, such as iron ingots, scrap, and lumps of coke, are removed from under the dropped bottom.

If the cupola operates for one or two shifts without halt, the lining burns out heavily. In this case the burnt-out bricks are replaced during the repair of the melting zone.

Firebrick lining is often changed for the ramming mixture composed of 80-85% quartz sand, 20-15% refractory clay, and 6-8% water. The ingredients are thoroughly mixed in the muller for 5-10 min. To increase the strength of the mix, liquid glass is added to water (1 kg to 1 l water). Rammed lining is more stable in operation than brick lining. During the repairs, the residues of iron and slag are first removed from the forehearth and then the lower part of the forehearth is cleaned. Next repairs are made on the taphole, slag hole, and the channel through which the iron goes from the crucible into the forehearth. The cupola spout should also be repaired after the heat: cleaned from skull and slag buildup and coated with refractory mass used for patching the cupola lining. The spout lining can be replaced fully if the need arises. The spout is dried out after repairs.

The hearth is rammed after completing the repairs to the cupola. In this operation, it is first necessary to close the drop bottom and then ram the filling sand in layers 40 to 50 mm deep to obtain the working bottom 150 to 250 mm in height. The taphole and slag hole are lined with refractory bricks. Two holes are then made in the brickwork, one being a working and the other an emergency hole which lies above the former. The diameter of the taphole depends on the output of the cupola and is generally equal to 12-30 mm. The slag hole is made larger in diameter (50-100 mm) because of the high viscosity of the slag.

Lighting up the cupola. Repairs and ramming of the hearth being over, wood shavings or cuttings and then pieces of dry wood are laid on the hearth through the cleaning hole. The hole is then walled up with firebrick, leaving a hole measuring one or two bricks in size (about 200 by 200 mm) to light up the heap and allow the air to get

access to the wood. The heap is set on fire with the peepholes (inspection holes) of tuyeres closed and the lighting hole open. After the wood leaps into flames, the first batch of coke is introduced into the furnace. The coke lumps must be homogeneous enough, 80 to 175 mm in size. Natural or producer gas supplied through the nozzles inserted into the cleaning hole or into open tuyeres can also be used for igniting the coke bed. Lighting with gas takes 25 to 35 min and with wood 1 or 2 h depending on the cupola diameter.

After the coke starts burning, a metal rod is lowered down into the coke to determine the coke bed height. The mark on the rod shows the height to which the coke bed should be raised with respect to the bottom edge of the charging hole. Coke is added to the cupola if the coke bed height is below the required level. Care should be taken to see that the coke forms a uniformly distributed column and does not lie on one side only. Under the height of the coke bed one understands a part of the coke column found to be above the tuyeres. In cupolas with a single row of tuyeres, the coke bed height is the distance from the upper edges of the tuyeres to the top of the bed; in cupolas with 2 or 3 rows of tuyeres, this is the column of coke extending from the highest row up to the top. The height of the coke bed above the tuyeres commonly ranges from 800 to 1 600 mm depending on the quality of coke, blowing rate, air-blast temperature, design and diameter of the cupola. The coke bed height is determined experimentally. If this height is chosen correctly, molten iron will appear near the tuyeres 5 or 6 min after turning on the blast. If the coke bed is too high, the iron will appear in 10-20 min or, sometimes, even later.

Putting on the blast and melting iron in the cupola. After charging the cupola to the bottom edge of the charging hole and holding it for some time to preheat the charge, the blast is turned on with tuyere peepholes kept open to guard against an explosion which might occur if the air has mixed with carbon monoxide which had forced its way to the blast box. One or two minutes after starting the blow, the peepholes of tuyeres may be closed. The taphole must be kept open until the molten iron rises up to the level of tuyeres (that is, for 5 or 6 min), following which it may be closed.

Charging the cupola. The charge consisting of metal, coke, and fluxes is dropped in alternate layers on the burning coke bed to form the charge column extending as far as the bottom edge of the charging hole. The batch of the coke split should be made up according to its volume rather than its mass. The most fitting height of the coke split is 150 to 200 mm. The height of the coke split and the cross-sectional area of the cupola are the parameters by which one determines the volume of the coke split and then its mass from the volume, considering that 1 m³ of coke weighs 450 kg. For example, if we assume that the cupola diameter D is 2 m and the coke

split height h is 0.18 m, then the coke split volume in m^3 is

$$V = \frac{\pi D^2}{4} h = \frac{3.14 \times 4}{4} \cdot 0.18 = 0.57$$

Hence, the mass of the coke split is $450 \times 0.57 = 257$ kg. By the coke split mass we can find the mass of the metal batch (a metal charge fed into the furnace at a time). If the coke split mass accounts for 12% of the mass of metal charge, then the mass of metal is $257/0.12 \approx 2140$ kg.

The amount of coke spent on metal melting depends on the type of castings. It averages 16% of the mass of metal charge. Thin-walled castings need hotter metal and thus a higher amount of coke. When running thick-walled castings, it is possible to bring savings in fuel by increasing the mass of metal charge. The correct charging of a cupola with metal, fuel, and fluxes effects the optimal run of the furnace. Since during the long heats the cupola lining burns back and the cupola inside diameter grows, particularly in the fusion zone, the height of the coke bed decreases, which factor disturbs the regular run. To restore the original height of the coke bed, one should introduce a coke booster after loading 15 to 20 batches of the charging materials into the cupola.

In fully mechanized cupolas, automatic machines and mechanisms carry out all the operations which involve loading, weighing, transporting, lifting the buckets to the charging scaffold, charging the furnace, and conveying the buckets to the stockyard. In the stockyard special hoppers (each for a definite kind of metal) load the drop-bottom buckets. Automatic charging scales weigh the metal charge. The skip hoist loader delivers the buckets on to the charging platform and the buckets discharge the metal into the cupola. Fuel and fluxes are charged into the cupola in a similar manner.

3.2. METALLURGICAL PRINCIPLES OF MELTING IRON IN THE CUPOLA

During melting of iron in the cupola, charge materials move in the opposite direction to gases. The charge materials sink to the hearth bottom and melt under the heat of gases, which in turn go upwards from the level of tuyeres and cool down, giving up heat to the materials.

Along with heat transfer, a great many of the chemical processes take place in the cupola.

The cupola may be divided into five zones (see Fig. 159): the shaft (zone I), the melting zone (zone II), the reduction zone (zone III), the combustion zone (zone IV), and the crucible (zone V).

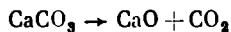
The cupola shaft. In this zone the solid metal only reacts with a hot gaseous medium to give Fe_2O_3 and Fe_3O_4 . Iron can also undergo

carburization, in which process carbon dissolves in the metal phase. The solubility of carbon in the γ -Fe system varies from 0.8% at 723°C to 2% at 1 130°C. The excess carbon is present as graphite or carbide.

These two phases can result from the reactions



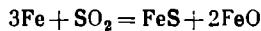
Oxidation tends to form gaseous products carried away from the surface of metal; here silicon and manganese oxidize to SiO_2 and MnO , which react with FeO to form an oxide film on the metal surface. Along with these processes, the metal surface absorbs sulfur, though the oxide film retards the rate of absorption of sulfur by the metal and its oxidation. As it heats up to 100°C in zone I, the fuel loses moisture and volatile substances, becomes loose and porous, and assumes a high reactivity. That is why the cupola fuel must contain a minimum of volatile substances. Limestone must be heated in zone I to a temperature sufficient to break it down completely by the reaction



Large lumps of limestone heat through poorly and thus weakly dissociate.

The melting zone. In this zone the pieces of metal heat up strongly and start melting. If the charge is well cropped, the melting of all metal pieces is finished in zone III, which is a weakly oxidizing zone since it does not contain oxygen. Larger pieces of metal may have no time to melt down in zone III and thus sink solid to zone IV, that is, to the combustion zone rich in oxygen which can heavily oxidize the metal. If the metal charge melts within zone III free of oxygen, then the metallurgical processes that occur in zone II become identical to the processes taking place in zone I.

In the period of melting, the metal is able to absorb sulfur by the reaction



much more intensely than it does so in the upper layers of the charge.

Gases in this zone remain stable in composition, but cool heavily because they give up heat to the metal, thereby causing it to heat up and melt.

The reduction zone. In this zone the droplets of metal become overheated at the expense of the heat of gaseous phase, mainly under the heat of burning coke. The atmosphere here is as weakly oxidizing as it is in the first two zones. Iron oxides being formed on the surface of a metal droplet dissolve in the droplet itself and give up oxygen to iron impurities (which have a stronger affinity for oxygen than iron), namely to silicon, manganese and partially to carbon. At the same time, as metal droplets come in contact with fuel, they dissolve

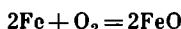
carbon and sulfur of the fuel. The reaction between the gas and fuel proceeds in the following manner: $\text{CO}_2 + \text{C} = 2\text{CO}$.

In this same zone liquid silica, SiO_2 , reacts with solid lime, CaO , forming slag.

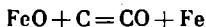
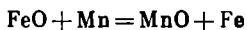
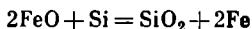
The combustion zone. The atmosphere in zone *IV* is more oxidizing than in zone *III* since it contains free oxygen. The droplets of metal get overheated as they take up the heat of gases and coke and the heat that results from oxidation of iron impurities by the gaseous phase. As they pass through the stream of cold air near the tuyeres, the droplets of slag cool down, while the iron droplets overheat at the expense of the heat of oxidation of impurities.

In the overheating zone the temperature is the highest, from 1 600 to 1 650°C.

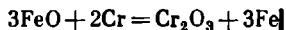
Iron oxidizes by the reaction



Oxygen then enters into reactions with the following elements:



Chromium, if any, oxidizes too:



Strong overheating of iron may arrest burning-out of silicon, manganese and chromium. The higher the overheat of iron, the more intensively carbon burns out, while liquid iron absorbs carbon from coke. In zone *IV*, sulfur contained in coke burns away, turning mainly to SO_2 .

The cupola crucible. The upper part of the well has an oxidizing atmosphere, the medium portion a weakly oxidizing and the lower portion near the hearth a nonoxidizing atmosphere. In zone *V*, the metal and slag cool as they lose heat to the walls and drop bottom.

The effect of gaseous phase depends on the level of metal and slag collected in the crucible. If the level of slag in a cupola without the receiver rises near or up to the tuyeres, the slag absorbs hydrogen and tends to oxidize the metal. The lower the slag level, the less oxidizing the atmosphere in the crucible. The deeper the well, the farther the slag level lies from the tuyeres, so that the metal oxidizes to a lesser degree, and vice versa. A thick layer of slag makes it more difficult for oxygen to get access to the metal and thus effectively prevents its oxidation.

In a receiver cupola (tank cupola), the melting loss of metal as it passes through the crucible is minimum. In the crucible, carbon goes on dissolving in the liquid metal if the carbon saturation has not reached its limit in upper zones *III* and *IV*. The limit of carbon

saturation may be considered to be the limit at which the carbon content answers to a eutectic composition.

The first portions of iron absorb sulfur released from the surface layers of coke lumps in the crucible. As it melts, the metal runs down into the crucible in separate droplets and streaks without intermingling. That is why in cupolas without a receiver a sufficiently good stirring of the molten metal does not take place.

Processes occurring in the receiver. Molten iron flows down from the hearth along the channel into the receiver where the streams of iron intermingle and iron components diffuse throughout the bulk, producing a more uniform composition of the iron.

As the metal passes through all the cupola zones, the elements which have a stronger affinity for oxygen than iron burn out to a greater extent. Practically, the silicon loss totals 20-25% and, sometimes, even more; the manganese loss runs as high as 25-30%, and the chromium loss 20-25%. Nickel, cobalt, and copper do not burn out at all. Carbon burns out, but at the same time iron absorbs carbon from coke; in the final analysis its saturation with carbon reaches a point indicative of a eutectic composition.

The need sometimes arises for melting low-carbon irons in cupolas. In this case the charge should contain steel scrap, and the cupola should have tuyeres located at a small height (250-300 mm) from the hearth to minimize the carburization of iron and its saturation with sulfur. The carbon content of iron produced in the cupola may be as low as 2.7-2.8%.

Low-carbon irons can be produced in cupolas with a firebrick bed. For this a part of the coke bed below the tuyere level is replaced by fireclay brick laid in staggered order. This part of the bed is pre-heated to a high temperature to decrease iron cooling. The charge blended with about 35% steel scrap can give iron with a carbon content below 2.2-2.3%.

Slags used in the cupola melting process. The cupola slag affects the course of melting and the properties of iron. The quantity and the composition of slag produced depend on the schedule of melting, quality of starting materials and fluxes, and also on the cupola design. In the process of melting, the sources of slag formation (3-4%) are the fuel ash that passes into slag, the irretrievable loss of elements Si, Mn, and Fe, the products of fused-off lining, sand and oxides that get into the cupola with the charge, and fluxes being added to lower the viscosity of slag.

The slag consists of silica, calcium oxide and alumina, the total content of which reaches 80 to 90% of all the mass of slag. The compounds of the types K_2O and Na_2O are present in small quantities (0.2 to 0.5%); phosphorus accounts for 0.1 to 0.5%, sulfur 0.2 to 0.8%, the balance being metal oxides. The slag also contains a small amount of iron, 0.2 to 0.5% of the charge mass.

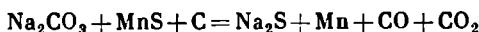
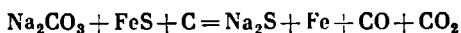
Cupola slag must have a low melting point and good fluidity, or low viscosity. A high content of iron oxides in the slag impairs the mechanical properties of iron, fosters porosity in castings, decreases the lining stability and increases the loss of elements in the cupola. The oxide of manganese, MnO, improves the mechanical properties of iron since manganese passes into iron, but an increased manganese content renders the lining less stable. The magnesium oxide, MgO, in an amount of 10%, gives strength to iron. The oxides such as CaO, Al₂O₃, and SiO₂, contained in the slag within permissible limits, do not affect the mechanical properties of iron. The slags poor in oxides do not change the form of graphite and the structure of the metal matrix. Slags erode the lining, therefore acid furnaces must not operate on basic slags, and vice versa.

For fireclay-lined cupolas, it is desirable that the slags have the following composition: 42-48% SiO₂, 10-15% Al₂O₃, 25-30% CaO; about 8% FeO; 2-5% MnO, and 3-5% MgO. Iron melted in the cupola can be enriched with phosphorus, manganese, nickel, and other elements by increasing the amount of oxides of these elements in the slag. It is necessary to use apatite-nepheline ore to introduce phosphorus, and manganese ore and open-hearth slag to enrich iron in manganese.

Methods of removing sulfur from iron. In running common cupolas under acid slags, the content of sulfur in iron depends on its content in the charge and in the fuel. It has been found that coke is the main source responsible for the saturation of iron with sulfur. The poorer the coke in sulfur, the less sulfur in the iron will pick up from it. Large coke lumps and a decreased quantity of coke in the charge make it possible to reduce the sulfur content of iron because the area of contact between metal and coke is small in this case.

The sulfur content of iron depends on the height of a coke bed (the smaller the coke bed height, the lower the sulfur content). The air blast introduced into the cupola aids in removing sulfur (SO₂) into the atmosphere.

To minimize the sulfur content, cupola iron is treated with soda ash and calcium carbide. An addition of soda ash is made in the iron-filled ladle or receiver to initiate the following reactions in the presence of carbon which acts here as a deoxidizer:



To keep sulfur from reducing and passing into the iron, it is necessary to coat the iron surface with powdered lime and then strike off the slag from the surface of the iron bath with a skimmer or remove it with a skimmer spoon. The amount of soda ash needed to treat one ton of liquid iron is 1 to 1.5 kg. The sulfur content of iron

decreases in this case by 30 to 40% of the total amount of sulfur found in the liquid metal.

In order that sulfur and phosphorus should be kept low, it is well to carry out melts in a basic cupola lined with magnesite, dolomite, and chrome-magnesite bricks. Such a lining permits the use of basic slags and enables a sharp reduction (by 40 to 60%) of the sulfur content of iron. The basicity of cupola slag is determined by the ratio between the percentages of basic and acid oxides in the slag:

$$\frac{\% \text{CaO} + \% \text{MnO}}{\% \text{SiO}_2 + \% (\text{Al}_2\text{O}_3 \\ + \% \text{MnO} + \% \text{FeO}} \\ + \% \text{SiO}_2 + \% \text{TiO}_2 + \% \text{P}_2\text{O}_5$$

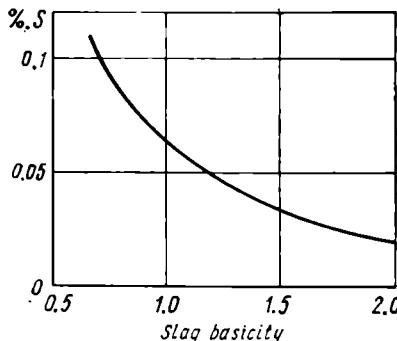


Fig. 160. Sulfur content of iron versus slag basicity

The conventional view has it that the slag with a basicity up to 0.8 should be termed acid, with a basicity within 0.8 to 1.2 neutral, and over 1.2 basic. Basic slags are divided into lowered, medium, and increased basicity types with a basicity of 1.3 to 1.5, 1.8 to 2.25, and over 2.5 respectively. The graph relating the sulfur content of iron to slag basicity appears in Fig. 160.

Running a cupola with a hot blast or oxygen-enriched blast also allows for a reduction in the sulfur content of iron.

To produce low-phosphorus iron in a basic-lined cupola, the slag must be high in CaO and FeO.

Limestone and iron scale or iron ore introduced simultaneously into the cupola to perform the function of a flux give good results. Here the slag basicity should be kept within 1.8 or 1.9. The greater the ferric oxide content of the slag, the higher the rate of dephosphorization of iron.

3.3. STEPPING UP THE PROCESS OF CUPOLA MELTING

The methods intended to intensify the melting process and thus to raise the cupola output of high-temperature metal with a minimum consumption of fuel involve control over the blowing rate, quantity and quality of fuel, use of hot blast and oxygen-enriched blast.

Optimal blast intensity. The blast input determines the height of a combustion zone and the combustion temperature. An increased air input speeds up the flow of gases so that the combustion zone elongates in a direction of the gaseous stream. Here the droplets of

iron negotiate a longer path in the high-temperature region and thus the iron overheats to a greater extent. Moreover, the temperature of gases grows in this case because the fuel burns up completely. Practical experience shows that the optimal blast intensity (the amount of air referred to a unit cross-sectional area of the furnace per unit time) must be equal to approximately $150 \text{ m}^3/\text{m}^2 \text{ min}$.

As the fuel consumption rises, with the blast intensity kept invariable, the crucible output diminishes, though the iron tempera-

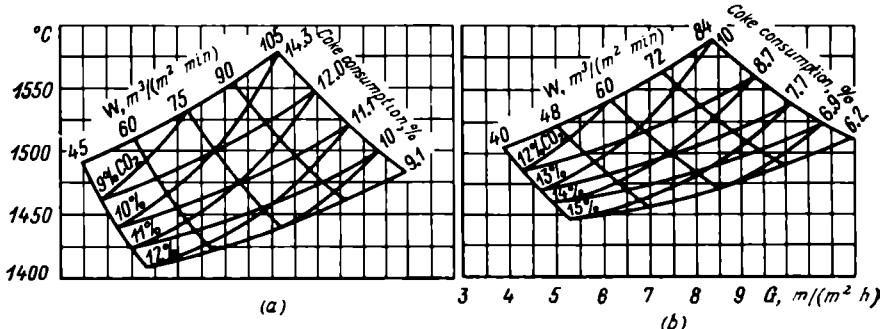


Fig. 161. Specific output of the cupola and iron temperature *versus* blast intensity and coke consumption with cold blast (a) and hot blast heated to 425°C (b)

ture increases since less iron passes through the high-temperature zone. An increase in the volume of either hot or cold air forced into the cupola causes the iron temperature and the cupola output to grow (Fig. 161). The speed of blast also has an effect on the cupola output and the temperature of iron. It has been established that iron melts more intensely at a speed of 2.5 m/s , which corresponds to a blast intensity w of $150 \text{ m}^3/\text{m}^2 \text{ min}$.

Fuel quality versus melting intensity. The quality of fuel depends on the size and density of lumps of coke, its reactivity, mechanical strength, ash and sulfur contents. The furnace operated on small-sized coke turns out less iron, consumes more coke per heat, and gives low-temperature molten iron high in sulfur. The larger the coke lumps, the greater the height of the combustion zone (see Fig. 159, zone IV) which effectively overheats the metal. But it is inadvisable to charge too big coke lumps (over 160 mm) since they form large air-filled voids conducive to heavy oxidation of iron. A 20 to 50% addition of thermoanthracite increases both the cupola output and the iron overheat temperature.

Blast heating. Blowing a cupola hot increases the temperature of iron and intensifies carbon burning since the hot blast conveys a rather large quantity of heat to the charge. This also raises the temperature of gases going through the coke bed and thus increases the

temperature of coke lumps in the bed. The process of heating and melting of the charge becomes more intensive with an increase of the temperature of the blast.

As the temperature of the air blast grows, the cupola consumes less coke, its output rises and so does the overheat of iron. From practical considerations, it is well to raise the temperature of the blast to 450-550°C and above. Figure 162 shows how the temperature of iron relates to the blast temperature with various consumption of coke. With the blast heated to 450-500°C, the temperature of liquid iron in the spout rises by 120-130°C.

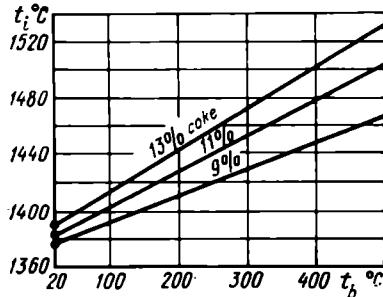


Fig. 162. Iron overheat temperature t_i as a function of air blast temperature t_b with various consumption of coke

3.4. DISTURBANCES IN THE CUPOLA RUN

Bridging of the shaft results from poor running repairs of the cupola and jamming of large lumps of a metal charge within the shaft. The skull protruding from the lining forms ledges which, if not properly removed, will hinder the downward movement of the charge, with the result that during melting the charge may bridge the shaft and hang up on the ledges. Inadequate cropping of the metal charge, that is, cutting of metal scrap to pieces over one-third the cupola diameter, may also lead to hanging (scaffolding).

With the metal charge being jammed, the coke bed burns away and the metal sinks into the tuyere zone still solid. If the bridge of jammed metal pieces cannot be broken down with a crowbar, the heat is stopped and the metal is forced downward with crowbars until it drops down on the coke bed. Next a coke booster consisting of two or more extra batches of coke is introduced into the cupola to form the coke bed of the required height.

Cold run of the cupola may result from inexpert lighting of the coke bed, low coke bed height, charge scaffolding, and so forth. The low-temperature molten metal will be unsuitable for casting into molds. A very cold molten metal may freeze the taphole. With the cupola running cold, it is necessary to introduce a coke booster (2 or 3 batches of coke). An emergency taphole (70 to 90 mm above the main taphole) should be available for tapping the molten iron if the main taphole has been clogged.

Explosions in the cupola mainly arise from accumulation of an oxyhydrogen gas which is a mixture of carbon oxide with air. The detonating mixture forms after terminating the cupola run; in the

idle period, gases (carbon oxide including) gain access to the wind belt and blast pipe through the tuyeres. With the peepholes of tuyeres kept close, the air mixes with CO and may form the detonating gas liable to blow up. With the peepholes of tuyeres held open, as CO leaves tuyeres, it oxidizes to yield CO_2 . The peepholes of tuyeres should be closed only after putting on the blast.

Stoppages of the cupola can be scheduled (for dinner breaks, shift changes) and unforeseen (in the case of emergency halt of conveyors and other types of machinery). If the prolonged run of the cupola has resulted in skulls, it is unsafe to shut off the blast for too long since the slag may clog (plug up) the free space of the shaft and stop the charge from moving downward. In the absence of skulls, the overheat of the cupola can be tolerated for several hours, but then one should preliminarily tap out the iron and slag from the cupola, close all the tuyeres, and seal off the taphole with molding sand so that the coke can cease burning. Sometimes, if the shutdown is expected to be very long, small-sized coke or charcoal is poured in on the charge in the cupola. Before turning on the blast, it is necessary to remove the plug closing the taphole and open the tuyeres.

Burnout of a cupola shell can result from damage to the lining in the zone of high temperature. In this case water is poured on the shell and then the work is continued. At the worst, the cupola is shut down, fettled, and the shell is cooled with water.

Breakout of hot metal through the hearth can occur if the rammed layer consists of a very strong foundry sand. On drying, the sand layer cracks and liquid metal gets into the fractures. A weakly rammed layer of sand can also be responsible for breakout. To guard against iron breakout, the drop bottom is cooled with a jet of water after turning off the blast and tapping out the iron. The burnt-through hole is stopped off with strong clay on the outside and covered with a steel plate resting on a prop. If the bottom burnout is insignificant, a layer of clay is enough to seal off the hole.

3.5. MELTING PROCESS CONTROL

A well adjusted process of melting in the cupola produces a sufficiently hot iron of the desired chemical composition and also ensures good technical-and-economic indexes.

The parameters to be controlled in the melting process are the quantity of metal, fuel, and fluxes charged into the cupola; the blast pressure and air volume intensity; the useful height of charge materials; the temperature of liquid iron; and the temperature and the composition of top gases.

Charge mass control. This is one of the major stages involved in controlling the melting process. The right proportioning of the con-

stituent parts of the charge (metal and coke batches, fluxes) ensures the production of iron of the precise chemical composition and of high temperature at a minimum consumption of fuel.

For weighing the materials to make up the charge and also to keep an account of the quantity of materials melted in the cupola, various weighing means are available, such as stationary charging scales, weighbridges, dial crane scales, and weigh cars.

Blast pressure and air volume control. Blast pressure control allows us to reveal changes in the resistance the air and gases experience while passing through the charge and to judge of troubles which may arise in the process of melting. Such malfunctions in the cupola run as a lowered height of the charge column, tuyere slagging, skull buildup, shaft bridging, and other defects largely depend on the blast pressure. The pressure of air forced by a blower into the cupola must be in excess of the atmospheric to overcome the opposition the column of charge material offers to the blast. The air pressure in the blast pipe is read from pressure gages. The excess pressure of air supplied to the cupola varies from 300 to 1 200 mm WC.

Charge level control. The normal height of charge materials in the cupola is equal to the distance between the upper level of the coke bed and the bottom edge of the charging hole. This column of charge materials causes a certain resistance to the motion of cupola gases and air forced into the cupola.

A lowered column of charge materials reduces drastically the resistance to the flow of air, with the result that the blast input grows and disturbs the regular conditions of coke burning: the charge sinking to the fusion zone fails to heat up properly. Such an erratic operation of the cupola retards the process of melting, consumes an excessive amount of fuel, causes heavy erosion (due to burnup) of the lining near the charging door and in the shaft and may subsequently lead to a drop of the lining at an extra low height of the charge column. In this case it is necessary to cut down the rate of blowing or turn off the blast at all and replenish the cupola with the charge materials up to the charging hole. Charge level measuring means include such devices as suspended weights dropped periodically into the shaft, contact charge level indicators, and also radioactive indicators.

Temperature control. Control over the temperature of liquid iron tapped out from the cupola makes it possible to obtain castings with high mechanical properties, preclude defects due to misrun, cold laps, cold shuts, slag inclusions, hard spots, gas cavities, shrinkage porosity, and others.

An important parameter of the cupola run is also the temperature of top gases. The normal temperature of the outgoing gases is considered to lie between 300 and 400°C. A temperature in excess of the above value points to an excessively high consumption of fuel or to

a low working height of the cupola. The temperature of iron, effluent gases, and air blast is measured by devices called pyrometers, of which most popular are thermocouple pyrometers and radiation pyrometers.

Thermocouples are used to measure the temperature of liquid metal (by immersing them into the melt) and also the temperature of off-gases (Fig. 163). In use are chromel *versus* alumel thermocouples to measure temperatures up to 1 100°C, platinum-rhodium *versus* platinum (to 1 400-1 600°C), tungsten *versus* molybdenum (to 1 800-2 000°C), and other thermocouples.

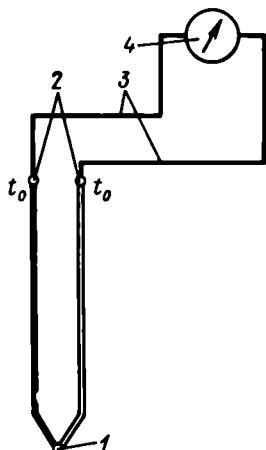


Fig. 163. Principle of a thermocouple

1—hot joint; 2—electrodes;
3—compensating leads; 4—galvanometer

Optical pyrometers measure the temperature of bodies heated to or above the red. They rely on the assessment of radiation intensity of hot bodies. Optical pyrometers come in two types, photometric and radiation. The first type is most widespread. The temperature measurements are made by comparison of the brightness of a hot source (liquid metal) with the brightness of the filament of a standard comparison lamp incorporated into the device.

During the measurements, objective 1 of the pyrometer (Fig. 164) is directed at a glowing object. The eye-piece 2 has a red glass 3 and a lens 4. The red glass enables the observer to perceive and evaluate only

the red out of the range of several colors. Looking into the eye-piece, the observer sees the glowing body under measurement and filament 5 of the incandescent lamp connected to a battery cell 6. A galvanometer 7 whose scale is calibrated to read degrees Celsius measures the current which can be varied by a rheostat 8 to control the luminance of the filament and thus secure a match between the colors of the lamp filament and the body under test. As soon as the filament becomes indiscernible in the background, the galvanometer will read the temperature of the body. When measuring high temperatures, a smoke glass 9 is set up between the lamp and the objective. The galvanometer has two scales, one for measuring temperatures in the range from 600 to 1 400°C and the other from 1 200 to 3 000°C (with the smoke glass).

A *radiation pyrometer* determines the temperature of a hot body by measuring its total radiation. This pyrometer constitutes a telescope bringing into a focus the flux of radiation from a liquid metal found in the field of view of the device. Located in the focus of the pyrometer is a heat-sensitive element, which consists of leads

of one or few thermocouples connected in parallel to form a thermopile. A thermal e.m.f. induced in the element is read off from a millivoltmeter.

Radiation pyrometers have scales calibrated to read directly the temperature of liquid metals from 900 to 1 800°C. For controlling the temperature of liquid iron, the pyrometer suspended from a bra-

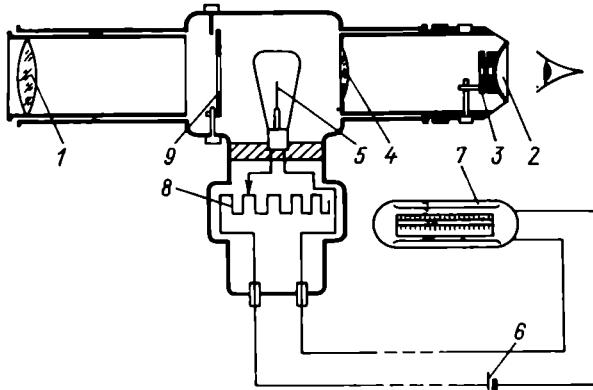


Fig. 164. Schematic of a disappearing filament photometric pyrometer

cket above the cupola spout is aimed at any of the points of the spout along which a stream of metal will flow during melting.

Top gas composition control. The basic constituents of cupola gas are CO₂, CO, O₂, and N₂. By the contents of CO₂, CO, and O₂ in the top gas we can judge of the degree of fuel combustion. The best indicator defining the degree of combustion is CO₂, the product of complete combustion. In controlling the completeness of combustion, therefore, the quantity of CO₂ in top gases serves as the basic parameter by which we can evaluate the effectiveness of fuel burning. The CO₂ content in a well operated cupola must be equal to 13-15%. The composition of top gases is estimated by gas analysers; it varies over wide limits. For example, gas No. 1 contains 16.5% CO₂ and 3% CO, and gas No. 2 has 5.1% CO₂ and 26.3% CO. The content of CO₂ and CO in gas No. 1 is indicative of the right ratio between the coke quantity and blowing rate, while this content in gas No. 2 points to an excessive consumption of coke or to a deficiency in the blast volume. If the top gases contain over 1-1.5% O₂, it is obvious that the blast input is excessi-

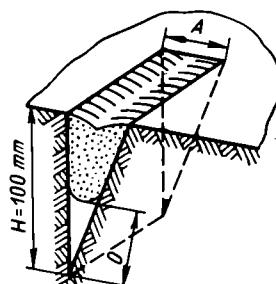


Fig. 165. Mold for casting a wedge-shaped chill-test specimen

vely high, the coke burns at an accelerated speed and much heat is wasted on the melt.

Chill test. This test is aimed at controlling the quality of iron in the process of melting, primarily for determining the susceptibility of cast iron to graphitization. The test consists in casting a wedge-shaped specimen 100 mm in height H and 20 to 50 mm in base width A in a green-sand mold (Fig. 165). For castings up to 25 mm in wall thicknesses, for example, the base width A must be equal to 20 mm.

A large depth O of chilling is an indication that castings in thin-walled sections will have hard spots. Such castings will be difficult to machine. A small depth of chilling evidences an increased content of carbon and silicon. This iron will have poor mechanical properties. The wedge-shaped specimens are also applicable for controlling the effectiveness of inoculation. The wedge is broken up to compare its fracture with the fracture of standard specimens. The edge of the wedge-shaped specimen usually has chilled spots on the fracture.

Chapter 4. MELTING IRON IN REVERBERATORY AND ELECTRIC FURNACES

4.1. MELTING IN REVERBERATORY FURNACES

Furnaces of this type are generally employed for melting iron low in carbon (below 2.8%) or for producing a large quantity of metal of homogeneous composition. These furnaces allow for the replacement of pig iron by large-sized scrap in considerable quantities.

Reverberatory furnaces produce malleable iron and also iron for rolling-mill rolls.

These furnaces range in size from small units to installations capable of holding up to 80 tons. The working bottom (hearth) consists of a rammed layer of sand mixture composed of 92 to 94% quartz sand and 6 to 8% refractory clay. The furnace roof comprises a number of arched sections, which are made movable for large-capacity furnaces to facilitate charge loading. The products of combustion go from the fire box into the working space above the charge placed on the hearth. The furnace can operate on pulverized fuel or oil. The metal charge can be either solid or liquid, the former being used to melt iron for rolling-mill rolls.

Low-melting charge materials are placed on the hearth closer to the back bridge wall, and large pieces of scrap and high-melting materials on the top, closer to the flame. Charge materials should be laid loose. The charge is first melted under heat of a short flame and then a long flame to refine the metal and bring it to the desired chemical composition.

The longer melting time and increased content of FeO decrease the susceptibility of rolling-mill rolls to chilling. Additions of ferrosilicon and ferromanganese to iron are made directly in the ladle rather than in the furnace to reduce the loss of ferroalloys. The melting loss of metal in a reverberatory furnace accounts for 5 to 7% of the charge. The slags normally contain 45-55% SiO₂, 5-20% Al₂O₃, 15-25% (FeO + Fe₂O₃), 10-25% MnO, and 5-25% (CaO + MgO).

For slagging admixtures and coating the lining, use is made of fluxes which include 3 to 6% fluorspar and 6 to 12% open-hearth slag. The slag constitutes 6 to 8% of the metal bath.

The optimal overheat temperature of plain iron used for rolls is 1 370-1 390°C, and that of alloy iron 1 410-1 420°C.

When melting the charge containing high-silicon scrap, it is advisable to blow the furnace with oxygen to increase the output of iron. Oxygen is introduced at a pressure of 118 to 147 MPa

(12 to 15 kgf cm⁻²) through a special tuyere immersed into metal to a depth of 100 to 150 mm. This procedure raises the temperature of metal from 1 250 to 1 430°C.

In running a furnace for refining liquid metal, it is usual to charge it directly from a cupola through a feed spout. The iron is tapped from the cupola at a temperature of 1 300-1 360°C, poured into the reverberatory furnace and brought to 1 450-1 480°C in about 2 hours. The melting loss in this refining process is as follows: 15-20% C, 5-10% Si, and 10-20% Mn. The contents of sulfur and phosphorus remain the same. Steel scrap, iron and ferroalloys serve as the additions to the liquid metal charge. A 0.02 to 0.04% aluminum addition acts as a dioxidizer. It is fed directly to the hot metal stream when pouring the metal into the ladle.

A reverberatory furnace must hold approximately 2 to 2.5 times more metal than the amount of metal the cupola can produce per hour. The furnace is preheated one hour (to 1 400°C) before tapping the iron from the cupola and 2.5-3 hours before pouring into molds. The process of molten iron heating, filling and refining in the furnace included, takes 1.5 to 2 hours. The amount of black oil spent per heat comes to 22-25% of the solid metal charge and to 10-15% of the liquid metal charge. The time it takes to melt the solid metal charge depends on the furnace capacity and usually ranges from 7 to 10 hours.

4.2. MELTING IN ELECTRIC ARC FURNACES

Arc furnaces used in foundries operate as independent melting units and as a part of a duplex-process layout that comprises an arc furnace and a cupola or an arc furnace and an induction furnace.

Arc furnaces are used for melting high-grade irons intended for special-purpose parts, particularly thin-walled and intricately shaped castings, and also for producing alloy cast irons, inoculated and high-strength spheroidal graphite iron. Electric furnaces offer a number of advantages. They ensure a low melting loss of elements, produce iron to the strict analysis with a lower content of impurities, provide for higher overheat, better working conditions, and prove more adaptable to mechanization and automation.

Arc furnaces can operate with solid and liquid charges. The furnaces range in capacity from 1 500 to 5 000 kg and over (up to 45 tons), using alternating current (12 500 A) at a working voltage of 105-130 V. The shell of arc furnaces can be acid and basic. Acid-lined arc furnaces have found most widespread application since they feature a high stability and low cost of the lining, draw less electric power per heat, consume a smaller amount of electrodes and can produce a pour in a shorter time period. Basic furnaces are most

suitable for melting alloy cast iron with high contents of aluminum (aluminum vigorously reduces silicon from silicon dioxides and erodes acid lining), manganese, and chromium, and also with a low content of sulfur, up to 0.04%.

The constructional arrangement of an arc furnace. The shell is a welded construction. The upper part of the furnace has a removable top (domed roof) with three holes for inserting graphite or carbon rods (electrodes) into the working chamber. Gaps between the electrodes and the refractory brickwork of the roof are sealed off with packing rings cooled with water (water coolers). The furnace has a work (charging) door. The pouring spout serves for discharging the melt into an awaiting ladle. The electrodes draw current from electrode holders furnished with mechanisms to reciprocate them vertically at a speed of 0.8-1 m/min. The furnace has a shape of a bowl mounted on swivels or other suitable means to tilt it smoothly forward for pouring at an angle of 40 to 45°. The back tilt at an angle of 10 to 15° serves in the removal of slag. The charging door is opposite to the pouring spout. Low-capacity furnaces are equipped with a side tilting mechanism, and large-capacity furnaces are complete with bottom mechanisms. The furnace roof is mounted on rails to move it aside for charging the furnace. In the basic process, the lining is laid with magnesite brick commonly placed on heat-insulating brickwork. The acid lining is laid with silica brick. The roof is made from silica or magnesite-chrome brick. The magnesite-chrome dome is much more stable than the silica dome.

In Fig. 166 is illustrated an arc furnace for melting iron and steel.

Preparing the arc furnace for a heat. Before starting the melt, the arc furnace is lined. The roof is laid with silica brick to a template and then faced with a refractory mixture consisting of 52% quartz sand, 26% fireclay, and 92% water. The hearth bottom and banks of the furnace are laid with silica brick, leaving a gap 50 to 60 mm wide between the shell and lining to fill the gap with ground silica brick. The furnace is walled up with dry-bonded brick.

Before hearth ramming, the brickwork of the hearth bottom is dried for 3 to 5 hours, following which the lining is faced with liquid glass to increase the bond between the layers of hearth. Next it is necessary to ram the hearth and banks, swing the roof into position, dry the furnace for 3 or 4 hours, then charge the coke and blow it through with compressed air to intensify burning.

After melting cast iron, tapping it out and removing the residues of iron and slag from the bath, one should make hot repairs to the furnace. For this the hearth and banks are fritted using the above composition. If the hearth have skulls, it is necessary to spray it with fluorspar to sever the skulls and then glaze in the hearth.

The melting process. The solid charge mainly consists of steel scrap with a recarburizer or pig iron and pig crap. In melting iron

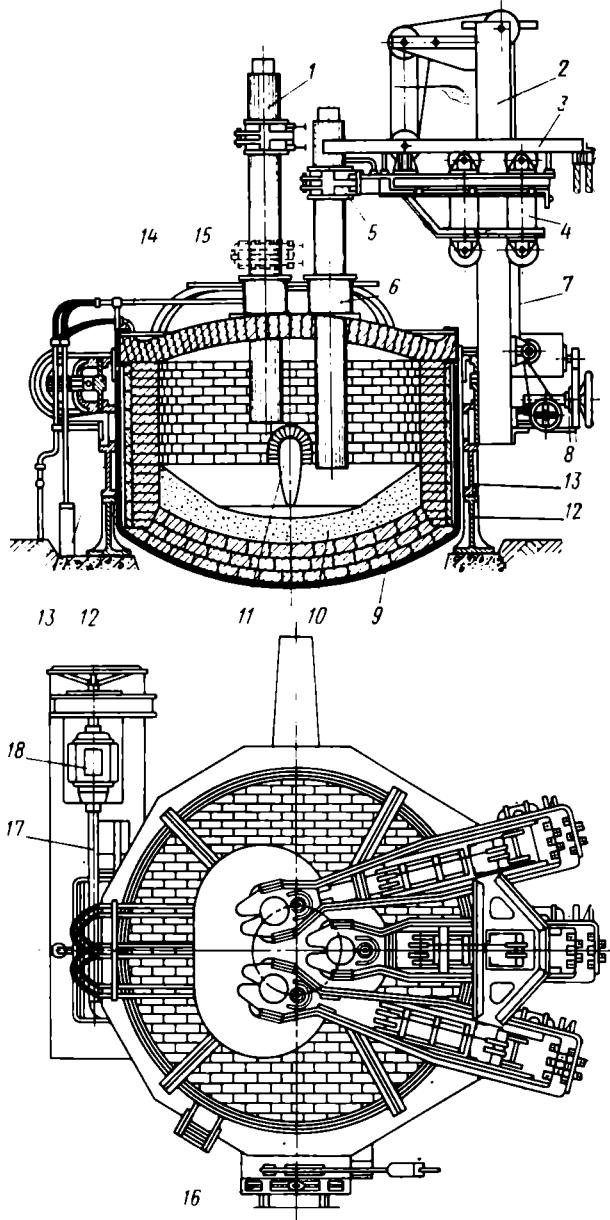


Fig. 166. Arc furnace for melting iron and steel

1—electrode; 2—guide pillar; 3—buses; 4—carriage; 5—electrode holder; 6—cooler; 7—steel-wire rope; 8—electrode-positioning mechanism; 9—steel shell; 10—rammed or fritted part of lining; 11—pouring spout; 12—toothed quadrant prop; 13—toothed quadrant for furnace tilting; 14—roof shell; 15—operating platform; 16—charging door; 17—tilting mechanism spindle; 18—electric motor

with a rebarburizer, large pieces of steel scrap are placed on the hearth, which are then covered with coke, charcoal or electrode scrap and lime (or limestone when melting in a basic-lined furnace).

The furnace is started up with the electrodes, connected in star, for approximately 5 min, until the arc struck from the electrodes on to the charge becomes stable.

During the melting of iron, the furnace is switched over from star to delta, and the charge is melted at full power under the layer of slag. To cut down the period of melting, it is necessary to shove off the charge from banks and sill, preventing the formation of bridges.

After melting down the charge, the bath is heated, slag skimmed off, a rebarburizing agent (such as electrode scrap in pieces not over 50 mm in size) poured in on the bath surface, and the metal is thoroughly stirred. The rebarburization being over, the pieces of ferrosilicon and ferromanganese are introduced into the bath. The metal is then heated to the desired temperature and poured out into the ladle.

The amount of rebarburizer spent on the melt comes to 5-10% of the mass of scrap. Its consumption depends on the degree of carbon conversion. The degree of rebarburization varies with the type of rebarburizer and its ash content. The best rebarburizer is electrode scrap. As the slag basicity and metal temperature during bath stirring grow, the degree of iron rebarburization rises. In remelting of iron, 0.3-0.4% rebarburizer is added to the charge to make up for the loss of carbon during the melting process. The loss of other elements of the iron is insignificant.

Iron is remelted under acid or basic carbide slag. Acid slag consists of 80% SiO_2 and 20% CaO , and carbide slag of 60% CaO , 25% CaF_2 , and 15% ground coke. The composition of final slag in an acid furnace is 55-65% SiO_2 , 5-25% CaO , 1-3% MgO , 5-10% FeO , 3-7% MnO , and 5-10% Al_2O_3 . In a basic furnace, the slag composition includes 15-20% SiO_2 , 50-60% CaO , 10-15% MgO , 1-2% FeO , 5-8% Al_2O_3 , 1-2% MnO , and 2-3% CaF_2 .

Remelting liquid metal. An arc furnace operates on a liquid metal charge to remelt it to white cast iron for further production of malleable iron.

In the duplex process involving the use of a cupola and an arc furnace, the iron melted in the cupola is poured into the arc furnace 1 to 1.5 hours before the next shift starts pouring the metal into molds. This time is enough to heat the molten metal to the desired temperature. After pouring out a certain amount of metal for casting into molds, new charges of liquid metal are regularly added from the cupola; the arc furnace must be filled with liquid metal at least to 70% of its capacity. The temperature of iron poured into the arc furnace is 1 350-1 380°C. The furnace uses 80-100 V as its normal melting potential. If it is necessary to heat up the metal fast, the

furnace is switched over to operate at a higher voltage, 120 to 130 V, for some 5 to 8 min.

In the process of remelting, one should see that the hearth does not break away, which is usually the case in the conditions of excessive metal overheating. The hearth erosion gives rise to thick slag and liberation of graphite from white iron. If the melt is lacking in silicon and manganese, additions of ferrosilicon and ferromanganese make up for the shortage; steel cuttings are added to decrease the carbon content. On refining the iron to the analysis and heating it to 1 460-1 550°C, the metal is ready for pouring into molds.

Remelting liquid iron on a basic hearth. After filling the arc furnace with a molten iron, one must drain off the cupola slag, add steel scrap and ferroalloys and make up the carbide slag introducing for the purpose 6 parts of lime, 2 parts of fluorspar and 1 part of coke in the process of iron heating. The quantity of carbide slag formed must average 20 to 30 kg to one ton of liquid iron. The iron is held under slag as long as is necessary to heat it up to the required temperature and reduce the content of sulfur to the desired level.

For melting a high-strength iron low in sulfur, the carbide slag is made up twice. To lower the content of carbon and silicon in liquid iron, it is well to add steel scrap (0.25% C and 0.25 to 0.3% Si) in amounts calculated on the basis of the initial and required contents of elements in the iron, disregarding the quantity of carbon the iron can pick up from the electrodes.

Liquid iron deficient in silicon is alloyed with ferrosilicon (45% Si) whose additions may vary in mass with the initial and desired silicon content of the iron and the silicon loss due to melting, which totals 15% of its mass in ferrosilicon. The 75-% ferrosilicon will do as well instead of the 45-% ferrosilicon, only the quantity of the former should be reduced by a factor of 1.6.

Basic working on iron takes more time, by 30 to 40 min, requires more power per ton of bath, 30 to 160 kW h, and greater amount of electrodes than when making iron in an acid furnace.

4.3. MELTING IN CORELESS INDUCTION FURNACES

Induction furnaces are used for melting iron from a solid metal charge, for preheating the iron and refining it to the analysis.

Induction furnaces work on the principle of a transformer: an alternating electromagnetic field induces eddy currents in the metal, so that electric energy converts to heat, whose quantity depends on the resistivity of the charge. If the charge consists of metal scrap, chips, and other metal rejects then eddy currents arise between separate pieces of charge because of high contact resistances. So, smaller charge pieces require increased frequency of current that feeds the induction heater in order to speed up melting of the charge. Other

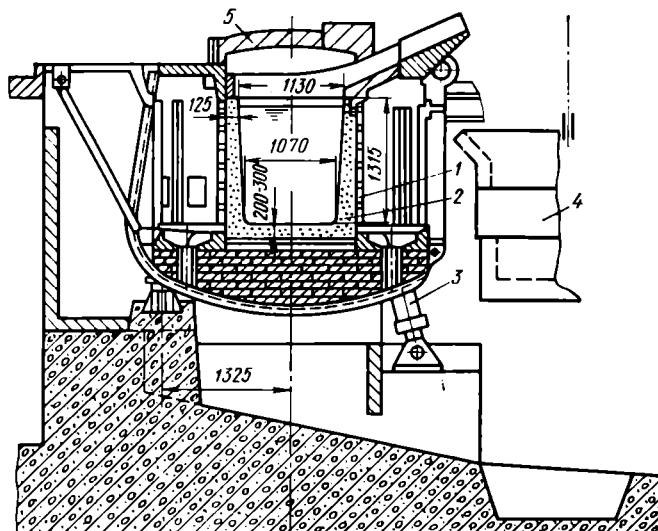


Fig. 167. Coreless induction furnace
1—induction heater; 2—crucible; 3—tilting mechanism; 4—ladle; 5—cover

conditions being the same, a higher frequency makes it easier to start up the heat with cold charge. Induction furnaces operate on currents of commercial frequency (50 Hz) or on currents of higher frequencies, from 500 to 2000 Hz.

What make induction furnaces beneficial in foundry practice are the low melting loss (under 5% C, 5% Si, and 10% Mn), the total loss being below 2 or 3%, use of loose chips instead of briquettes, and improved working conditions.

Foundries employ both coreless and core induction furnaces. The first type enjoys most widespread uses. *Core-type, or channel, induction furnaces* are suitable for heating iron and steel. Induction furnaces of a capacity of 40, 60 t and over with three removable inductors find use in combination with cupolas (in the duplex process).

Figure 167 shows an 8-ton capacity coreless induction furnace.

An induction heater constitutes a single-layer multiple-turn primary coil made of water-cooled copper tube. The working voltage is impressed across the terminals (ends) of the coil. These furnaces have a great many applications: for melting irons, steel, and non-ferrous metals. In wide use are high-frequency vacuum furnaces to melt steels with a low content of gases and harmful admixtures.

Preparing a coreless induction furnace for a run. This type of furnace has a rammed acid lining. The initial materials for ramming

the lining include 48% quartz (by volume) of a grain size from 5 to 15 mm (the content of SiO_2 being not less than 95%, with a minimum of Al_2O_3 and Fe_2O_3), 50% ground quartz of a grain size not over 1.55 mm, and 1.8% boric acid. Quartz is dried at 250-150°C and then screened through a sieve. Ground quartz and boric acid must be dry. Boric acid is screened through a sieve of 0.5 mm mesh size. The lining compound is mixed dry and then riddled through a sieve 5 mm in mesh size. The ready mixture must be used for ramming as quickly as possible since boric acid absorbs moisture (the storage time of the prepared mixture must not exceed 15 h).

Before ramming the crucible lining, one should inspect and test-operate the tilting mechanism, check the induction heater for reliable fastening, and also pump water through the inductor coil at a certain pressure to reveal possible defects (leaking, clogging, and so on).

Before starting up the heat, it is necessary to examine the crucible bottom, the putty between the coil turns and all the places between wooden braces and asbestos sheet. The damaged coat between the coil turns should be sealed off with the paste composed of three parts alumine cement, one part dry sand, and one part ground clay. On the inside, the inductor should be coated with asbestos sheet 3 to 5 mm thick. Next the crucible bottom should be covered with asbestos sheet 6 to 10 mm in total thickness and sprayed over with fine-grained quartz sand riddled through a 2-mm mesh sieve. The crucible bottom is rammed in layers, each 50 to 70 mm thick. Before ramming the subsequent layer of sand mixture, one should loosen the preceding layer to a depth of 5 mm to obtain a strong bond between the layers.

What is required to do next is to place an iron sheet template on the rammed bottom and pack the lining in layers 30 to 40 mm thick in the gap between the template and the insulated coil of the induction heater. The drying of the rammed lining then follows, during which process the inductor is filled with water and checked every 30 min. If the coil sweats, it should be dried by compressed air. During drying and melting the temperature of outgoing water must always stand at about 35°C. The crucible should be dried by current-produced heat during 4 hours (for one-ton capacity crucible).

To minimize the consumption of electric power and cut down the melting period, the crucible wall must be as thin as possible. While running the furnace, one must keep watch on the state of lining since it operates under most unfavorable conditions: the inside of the crucible lining is in contact with liquid metal, while its outside surface contacts the water-cooled inductor. Induction furnaces holding up to 30 t metal generally have rammed lining. The shortcoming of such lining is a large volume of work involved in its ramming. Large-capacity induction furnaces are lined with refractory brick.

Charging. One should place metal pieces on the bottom gently, avoiding impacts, into a compact heap. The metal pieces should be cut to size that provides good compaction of the batch without leaving spacings between the metal lumps and crucible walls. This offers an advantage of quick fluidizing of the charge with a minimum of power spent in this stage of the heat. The zone of the highest temperature during the melt lies in the lower part of the crucible, therefore it is practical to place first high-melting scrap on the crucible bottom. Large and high-melting pieces should stand parallel and close to the crucible walls, while low-melting components should be in the middle of the crucible. Small-capacity furnaces are loaded manually, and large-capacity furnaces with the aid of buckets.

Melting. At the beginning of melting, the furnace works for 5 to 10 minutes at a lowered power until the surges of current fed from the generator disappear. The furnace power is then brought up to a maximum. The charge melts with the crucible held closed. When the charge approaches the fluid stage, the furnace is switched off and solid pieces are pressed back with a crowbar. The furnace is then loaded to capacity by adding small-sized preheated pieces of metal. Steel scrap is usually charged into a fluid bath, and ferroalloys into a well heated bath whose temperature approaches 1 430-1 450°C. For carburizing the iron, large pieces of electrode scrap (1 or 2%) are placed on the bottom and small-sized pieces are dropped on the surface of metal after skimming off the slag. The operator should wear rubber gloves and goggles and stand on a rubber mat while slagging the furnace preliminarily disconnected from the supply.

4.4. MELTING IN CORE INDUCTION FURNACES

Cored (channel-type) induction furnaces make suitable melting units for the production of iron. They find effective uses in the making of castings from gray, malleable and high-strength irons, and also in the duplex process where a core induction furnace operates in combination with a cupola.

A core induction furnace (Fig. 168) consists of two main parts, the bath that acts as a metal receiver and closed-type melting channels where the metal heats up. A drum-type furnace comprises a cylinder 2 with two walls 7, which serve as bearing elements of the furnace. The drum rotates about its horizontal axis on rolls 1 from a chain transmission 3 powered by an induction motor 4. The breaks can stop the rotational motion whenever necessary. Siphons 8 provided in the lining walls are holes for pouring molten charge into the working chamber. These pouring holes effectively keep the slag from getting into the bath, thereby prolonging the life of lining. The dome has plugged-up holes 5 for introducing additives and skimming the slag.

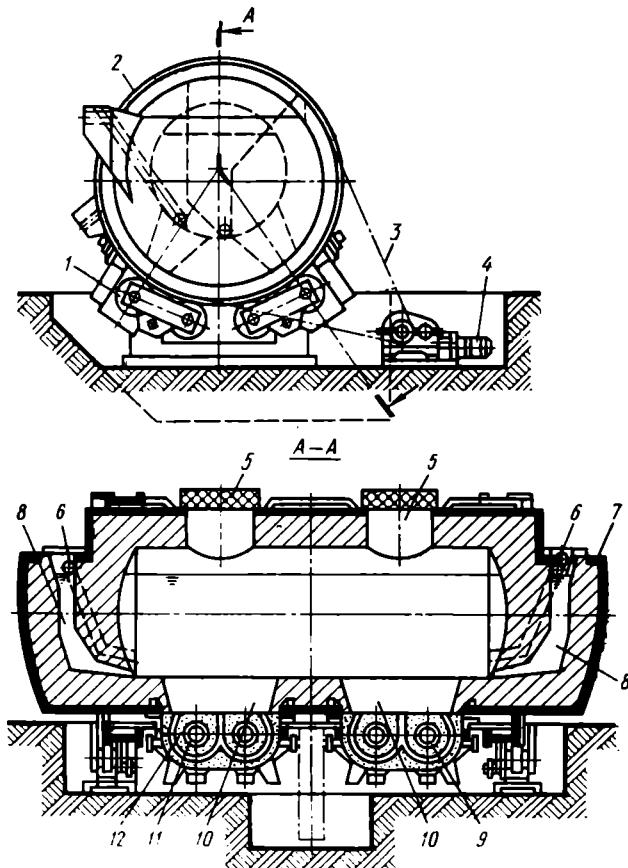


Fig. 168. Core induction furnace

The refractory lining of the bath consists of several layers. The outer layer is heat-insulating brickwork. Next layers are laid with fireclay brick. The working part of the bath is rammed to a metallic template with an alumina mixture consisting of 81% Al_2O_3 , 18% SiO_2 , and about 1% TiO_2 and Fe_2O_3 . Channels 6 serve to tap out the metal, take samples, and measure the metal temperature. Holes 10 connect the melting channels with the bath.

Heating of metal in the furnace is based on the principle of a single-phase transformer. Induction heater has an iron core 9 with primaries 11 encircled by U-shaped channels 12, being the secondaries in which the electromagnetic field induces a current that heats the metal.

The furnace lining is dried by gas burners. The temperature is raised slowly, 10°C in an hour, to $1\ 000\text{-}1\ 250^{\circ}\text{C}$, and held at this level for 6 days. The rammed siphon is first heated slowly by a gas burner to 150°C and then very fast to 750°C , and held at this temperature for 6 days. The drying temperature is measured by a chromel-alumel thermocouple and recorded.

In carrying out the duplex process (the cupola coupled with the core induction furnace), it is possible to fill in the induction furnace and tap out the iron simultaneously or at certain intervals, since the furnace can work both continuously and periodically. Additions to the iron are made in the cupola spout, or in the furnace siphon, or through the top holes; inoculants are introduced directly into the ladle before running the castings.

In the continuous process, the chemical composition and temperature of the iron remain stable owing to a large accumulation of metal whose volume exceeds 2.5-3 times the hourly output of the cupola. This is obviously an advantage of the process since it is sufficient to have only one electric furnace. The electric furnaces give metal of a more homogeneous chemical composition and of a more stable temperature if they operate on a periodic basis (in which process one electric furnace receives the molten charge and the other refines the iron for pouring).

Chapter 5. RUNNING, SHAKEOUT, FETTLING AND ACCEPTANCE OF GRAY IRON CASTINGS

5.1. POURING INTO MOLDS

The molds made ready for pouring are arranged on a mold setting platform or roller conveyors, on movable conveyors, or a movable casting platform.

Ladle types, lining and drying of foundry ladles. A ladle serves for transporting molten metal and pouring it into molds. It is a steel-plate vessel lined on the inside with refractory material 65 to 180 mm in thickness, such as fireclay for holding iron, and fireclay or magnesite for steel.

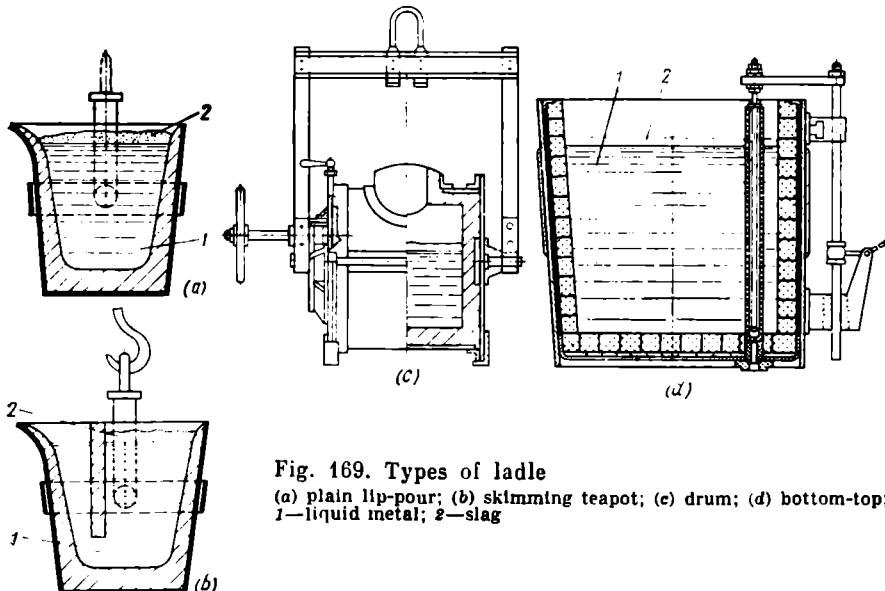


Fig. 169. Types of ladle

(a) plain lip-pour; (b) skimming teapot; (c) drum; (d) bottom-top;
1—liquid metal; 2—slag

By design, ladles come in a variety of types. There are lip-pour, teapot spout (skimming), drum, stopper, and other ladles (Fig. 169). For pouring iron, lip-type, teapot or teapot spout (siphon-pour) ladles find most widespread uses. For running medium- and large-sized steel castings, bottom-pour (stopper) ladles are most suitable.

Drum ladles commonly serve to run thin-walled small and medium-sized castings (where it is essential that the temperature of liquid metal should be kept stable), and also as feeder (distributor) hoppers

for filling in small ladles to be used for casting metal into molds. These ladles can hold 250 to 5 000 kg metal.

Teapot spout and stopper ladles keep better the slag from getting into molds than drum ladles and plain lip-pour ladles.

Lip-pour ladles are used to fill molds set up on conveyors. They are charged with metal poured from large distributor teapot ladles, stopper ladles, or from teapot receivers.

Stopper ladles differ in capacities, from one ton to a few tons, or even to a few tens of tons.

Depending on their capacities, ladles are transported manually, by means of overhead monorails, jibs, or overhead travelling cranes. Ladles holding up to 20 kg are hand shanks, or hand ladles (also called pouring cups) with one shank handle used for carrying molten metal by hand. A ladle of 50 kg capacity is a two-man tackle with two hand shank handles.

The lining layer thickness depends on the inner diameter R of the ladle in its upper part. The lining thickness of walls should be equal to $0.14R$, and that for the bottom to $0.2R$. The lining thickness of a ladle has to diminish somewhat from the bottom upwards. Much attention should be given to the lining of the bottom-pour mechanism comprising a stopper rod with a stopper end and a sleeve (nozzle). The lining is also made from a rammed mixture of 60 to 70% quartz sand and 30 to 40% refractory clay. The moisture content of the mixture is 8 to 12%. Drum and open-type ladles of 500 to 5 000 kg capacity and over are lined with fireclay brick bonded with the mixture of the same composition as used for coating of ladles.

Drying and preparation of ladles for service. Ladles are heated and dried with torches run on natural gas. First temporary repairs are performed to the ladle lining: slag and metal skulls are removed together with the lining pieces and then the lining is patched, dried, and heated. In major repairs the lining is removed completely and the ladle is given a new coat of refractory material.

Before filling the ladle, its lining is heated to 500-600°C, or 700-750°C for casting into molds which require the iron of very high temperature. Ladles are filled with metal just after heating.

Pouring molds. Before being cast, the iron should be cleaned of slag. The heat lost by iron during its tapping from the furnace, transportation, and pouring from one ladle into another should be taken into account, if necessary, in order to pour the iron of the specified temperature into molds. The advisable pouring temperatures of iron are given in Table 53.

The temperature loss of iron reaches 20-40° when tapping it from the cupola, and 30-50°C during reladling.

When casting into molds, the molder must keep a close watch on how the stream of melt flows from the ladle into the mold. At the initial period of casting, the molder should tilt the ladle smoothly

Table 53
Pouring Temperatures of Iron

Iron	Casting wall thickness, mm	Pouring temperature, °C	Iron	Casting wall thickness, mm	Pouring temperature, °C
Gray and high-strength	<4	1 450-1 360	Malleable	<4	1 480-1 450
	4-10	1 430-1 340		4-10	1 450-1 380
	10-20	1 400-1 320		10-20	1 430-1 360
	20-50	1 380-1 300	High alloy, ferrosilicon	—	1 300-1 270
	50-100	1 340-1 250		—	—
	100-150	1 300-1 230		—	—
	>150	1 280-1 220	Manganese-alloy, non-magnetic	—	1 350-1 280
				—	—

without jerks, but sufficiently fast to fill in completely the gating and the pouring cup. Following this, the molder should tilt the ladle at such a rate as to keep the level of melt in the cup invariable, if possible. The molder should exercise particular care at the end of mold filling; as soon as the metal has appeared in the flowoff, he must slow down the speed of ladle tilting to keep the melt from flowing over the cup and flowoff.

In casting the metal into molds, one should strictly observe the safety rules:

(1) the ladles should be filled with metal not over 7/8 the ladle height;

(2) the ladles over 500 kg capacity should be furnished with tilting and turning mechanisms which have self-braking worm gearing;

(3) the rails along which the metal-filled ladles travel to the casting platform should have no tilt;

(4) passages and paths should be kept dry since liquid metal splashed out on to the wet floor may cause explosion;

(5) the pourers should have on working clothes: canvas jackets and trousers worn over high felt boots or other special footwear, gloves, headwear, and protective glasses.

Automatic casting. Pouring-in is one of the labor-consuming and complex operations involved in the production of castings. It requires high accuracy of metal batching and much care and alertness on the part of operators; the pourers work in heavy conditions,

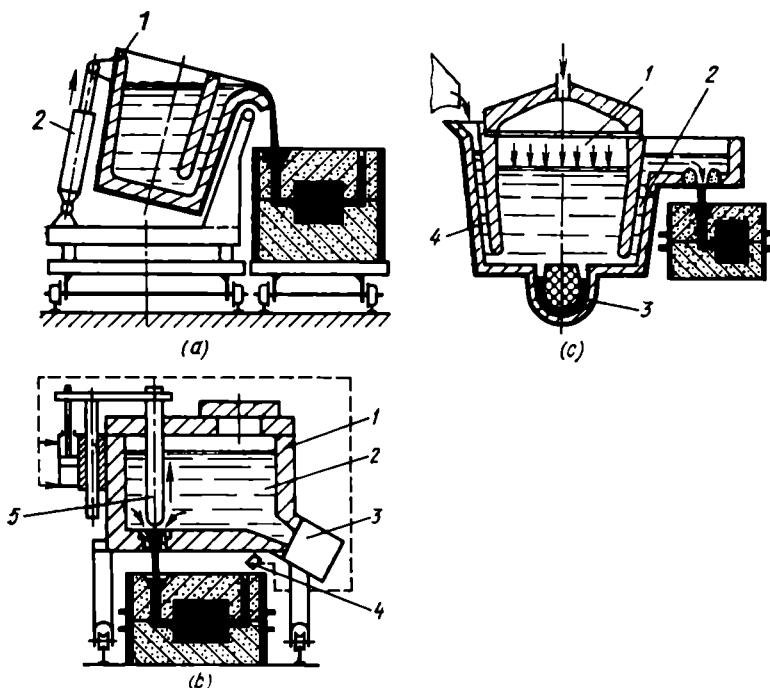


Fig. 170. Principle of arrangements for automatic pouring into molds

under exposure to intensive thermal radiation, streams of gases evolved from the molds during pouring, and run the risk of sustaining burns from splashes of liquid metal. Automatic casting rules out many of the above difficulties. Automatic molding lines make wide use of casting arrangements (casters) shown in Fig. 170 in schematic form.

The pouring unit (Fig. 170a) has changeable ladles 1 set up in a hydraulically operated hoist 2 being put into motion by the pourer from the control desk. A change in the angle of ladle tilt allows control over the pouring rate. The time of filling the mold or the known mass of metal provides for metering out the required batch. These casters are successfully used in running iron castings. But they are not suitable for casting steel because of the formation of skull in the mouth of a ladle (a ladle spout, or lip). These units can serve as single-position and double-position stands which have found extensive application.

A casting machine shown in Fig. 170c has a distributor chamber 1 where melt 2 is kept hot by a circular induction heater 3. Raising a stopper rod 5 to a desired height secures control over the pouring

rate; the time of pouring or the mass of metal being tapped out secures the required portion. The stopper rod closes the ladle nozzle in response to a command received from a photocell 4. These machines are employed for casting nonferrous metals.

In a casting arrangement shown in Fig. 170b, a vessel 1 has a ring-type inductor 3 to heat and stir the melt and an airtight cover. The vessel periodically receives the molten iron through a channel 4. To pour out a desired amount of metal, it is necessary to build up pressure above the metal surface and thus raise the level of melt in channels 2 and 4. The metal then flows over through the ladle spout and into the mold. The gas pressure above the metal surface secures control over the pouring rate. The pouring time and metal mass provide for metering out the batch.

Control and adjustment of casting machines with a stopper rod and a gas pressure regulator are complicated operations, for which reason these machines find use only in mass and large-batch production.

Casting stands for automatic pouring with manual remote control are more readily adjustable, easier to handle, and permit installing them in safe zones, thereby facilitating the pourer's work and improving operating conditions.

5.2. COOLING AND SHAKEOUT OF CASTINGS

After pouring a mold, the casting cools and solidifies. The completely solidified casting must be allowed to cool for some time in the mold since the metal has low strength at high temperature and the casting may warp or break up while shaking it out from the mold. Moreover, it is undesirable to strip the mold from the hot casting because it cools nonuniformly in the air: thin sections will cool much faster than massive portions. This will give rise to internal stresses, warping, and even to the formation of cracks. To obviate the defects associated with the appearance of internal stresses in castings, these should be knocked out at a temperature below the point Ar_1 (723°C) at which all the transformations in the metal come to completion.

Thin-walled iron castings are removed from molds at 400°C , moderately thick castings at 500°C , and thick-walled castings at 600°C . In the production of malleable iron, white iron castings should be shaken out at a temperature under $760\text{--}800^{\circ}\text{C}$. Castings whose temperature is below Ar_1 become brittle because they have the structure of white iron (pearlite and cementite). In castings pushed out of molds at above $1\,000^{\circ}\text{C}$, cracks are liable to appear since white iron has not time enough to solidify in thickened portions.

The time required to hold castings in the molds to allow them to cool to the specified temperature may be very long; the holding for large castings can range into several days and nights, which reduces

the output of foundry shops. Forced cooling by water, air-water mixture, or just by the jet of air can cut by half the period of cooling to the desired temperature without impairing the quality of castings.

In practice, foundries often resort to a method which enables a high-temperature shakeout of castings, at 700–750°C, with the subsequent cooling in pits, wells or other suitable cooling installations. The shakeout operation is safe to perform only at the temperature which ensures the sufficient strength of metal. In flow and mass production, it is possible to control the shakeout temperature by adjusting the speed of the molding conveyor, taking into account its path length. If a casting in the mold is not able to cool down as it covers the path on the conveyor from the pouring station to the knockout grid, then the casting has to make two runs. If this does not help, it is necessary to lengthen the conveyor or install a roller conveyor to remove the filled molds from the working conveyor for cooling.

The *shakeout process* consists in removing a solidified and cooled casting from the flask and breaking out the mold to take off the casting, knock out the cores, and subsequently cut off gates and risers. The final operation involves cleaning the outside and inside surfaces of castings from the burnt-on sand. The shakeout is one of the most labor-consuming and arduous operations. The molds being stripped from castings evolve much heat and gases. The dust-laden atmosphere is harmful to the health of operators. In this connection automation and mechanization of shakeout and fettling operations are the task of paramount importance.

The grids employed for shakeout operations are most often of the pneumatic, mechanical, eccentric, and inertia types. Mechanical, eccentric, and inertia grids are most economical and, besides, produce less noise.

In foundry shops making castings in large batches and on a mass scale, automatic and semiautomatic machines handle the core and mold knockout operations and convey the castings to the fettling station.

5.3. FETTLING OF CASTINGS

Castings are conveyed to the fettling (dressing) shop for finishing operations such as cleaning, cutting (sawing, chipping, flogging, flame gouging, and so on), and trimming (grinding). These operations are performed in a definite technological sequence that depends on the characteristic features of castings, such as the chemical composition, mass, wall thickness, metal properties, and requirements placed on the castings. Before being cleaned, the castings are examined for obvious defects due to misrun, drop in the mold, cold laps

and cold shuts, and others. Defective castings are put aside as they are not destined for cleaning.

The **fettling** process includes the following operations: decoring, removing gates, flowoffs, and risers; stripping off adhered sand from castings; trimming burrs, ribs, and scale after heat treatment; straightening and painting the castings (if the production process calls for these operations), inspecting for acceptance after cleaning and cutting.

Decoring, or *core knockout*, is a labor-consuming operation. The labor input involved in the removal of cores from solidified cast-

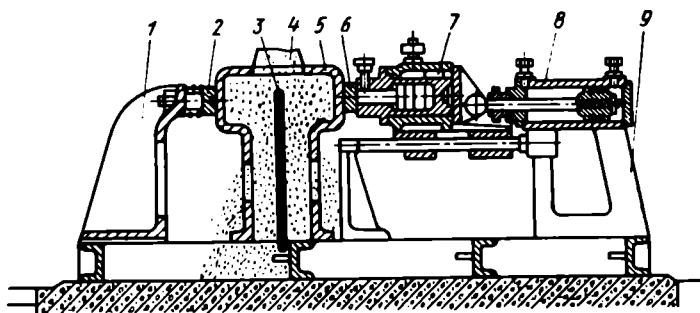


Fig. 171. Core vibrator

1 and 9—front and rear supports; 2—spring stop; 3—core iron; 4—core; 5—casting; 6—vibrating rod; 7—vibrator mechanism; 8—air cylinder clamp

ings largely depends on the retained strength of core sands, shape of the casting cavity, and the stressed state of the core in the casting. Cores prepared from sand mixtures with organic binders (oils, oil substitutes, and synthetic resins) have low retained strength and good collapsibility. In many cases, therefore, cores (especially of simple shapes) are knocked out from castings in the process of stripping the castings from molding sand on the knockout grid and in the course of cleaning castings in shotblast installations. But rather large cores, even those made from sands bonded with synthetic resins are removed on shakeout machines.

Cores made from liquid-glass bonded sands, liquid self-setting mixtures, plastic self-setting mixtures, and loam sands show poorer collapsibility than organic-bonded sand cores.

There are various decoring machines such as core vibrators, water-jet core knockout units, and others.

A core vibrator (Fig. 171) has a pneumatic vibrating mechanism that shakes a casting and thus breaks down the core whose fragments drop out of the casting cavity. The cores made from loam sands, liquid glass-bonded, liquid and plastic self-setting mixtures are dif-

ficult to shake out on such machines. Hydroblasting installations are more suitable for the purpose and find common uses especially in shaking out cores from large castings. A jet of water, forced under a pressure of 9.8 to 19.6 MPa (100 to 200 kgf cm⁻²), breaks down the core into pieces and at the same time cleans the casting surface (Fig. 172a).

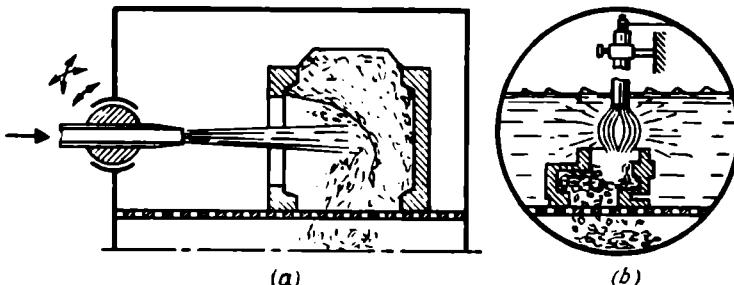


Fig. 172. Core shakeout methods
(a) hydroblasting; (b) electric-discharge hydroblasting

An electric-discharge hydroblasting method for core shakeout and cleaning of castings rests on an electrohydroblasting effect which results from a high-voltage discharge in water between a special electrode and the surface of a casting. Impact waves induced by the discharge break down the core and the sand layer adhered to the casting and thus clean the casting surface (Fig. 172b).

Electrohydroblasting installations can handle steel, iron, and nonferrous alloy castings in the piece, small-lot and large-lot production. They find most advantageous use as core shakeout units for medium-sized and large-sized castings.

The electrohydroblasting method has the following advantages: secures high productivity and effectiveness, excludes hard manual work, and decreases the dust content of air in foundry shops.

Removal of gates and risers. Gates are cut off on circular and band hacksaw benches and on chipping presses.

Risers and extra pads are removed from steel and iron castings by power hacksaws, band saws, and on disk-type cutting benches. These benches cut off risers in the following manner. As a fast-rotating thin water-cooled disc bears against a casting the contacting surfaces evolve much heat as a result of friction. The metal becomes plastic and easily cuts by the disc.

In use are also various presses for cutting gates, such as hydraulic, crank, friction, and other types. As the punch executes a forward motion, it cuts off the gates and thus frees the casting from the sprue. Hydraulic and friction presses find also use for cutting the studs of gates from malleable iron castings after annealing.

Electromachining makes a suitable method for cutting flow-offs, gates, and risers from high-alloy steel castings. In an electrolytically assisted cutting-off machine, the casting is connected to the anode and the tool to the cathode of a d.c. circuit. The cutting zone receives a water solution of liquid glass of a density of 1.27 to 1.30 g/cm³. The tool in the form of a disc or a circular band, while being put in motion, can be adjusted for a certain depth of feed. As the d.c. circuit closes through the projections on the casting, the cutting process begins. At the places where the casting makes contact with the disc, the microprojections melt down and the disc carries away the products of melting in the form of beads. The electromachining

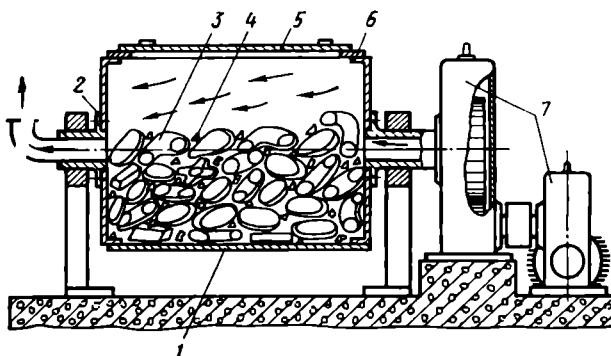


Fig. 173. Tumbler for cleaning small castings

1—shell; 2—trunnion; 3—casting; 4—picks; 5—lid; 6—cast-in flanges; 7—drive

method gives a narrow width of cut, smooth surface, ensures low metal waste and rather high operating efficiency.

Abrasive cutoff wheels are effective for cutting off risers and gates in that they give an even and clean cut and make little noise in operation. But this cutoff method has limited applications since it makes the air heavily laden with dust, requires many abrasive wheels and involves difficulties in adapting it for grinding large castings.

Flame cutting uses acetyline, gasoline, kerosene, and, rarer, hydrogen for burning in the stream of oxygen. The flame heats and burns out the metal in the place of cut and thus removes the gates and risers.

Arc cutting provides a means for removing gates and risers from heat-resistant and acid-resistant steels, which are not amenable to gas cutting. The surface of cut becomes rough and needs additional treatment.

Removal of burnt-on sand and scale. *Tumbling barrels* of periodic action serve for cleaning the outer surface of small castings (Fig. 173) produced piecemeal and in mass quantities. The process of cleaning

consists in rubbing of castings against white iron picks (stars) loaded into the tumbler in an amount of 20 to 35% of the mass of castings. Small castings up to 30 kg in mass are charged in batches into the drum, while larger and thin-walled castings are laid piece by piece.

The time of cleaning depends on the shape of castings, kind of metal, and the method of loading castings into the drum. The rotational speed of the drum is 30 rpm. Tumbling peels off the adhered sand and breaks away flash (fins) built up at the parting joint and at the core prints. The tumbler handles 800 to 1 300 kg of castings per hour.

Tumblers of continuous action clean small mass-produced castings. The shakeout of cores and removal of gates and fins in the drum occurs as the castings rub one against another. The drum rotates at 20 rpm with a tilt of 1.5 to 2° to the horizontal to ensure the movement of castings along the drum axis.

Shotblasting is the process of cleaning castings in drums and chambers (shot blast cabinets) by a jet of blasting shot—rounded grains of iron 0.8 to 2.5 mm in diameter thrown out at a speed of 20 to 30 m/s by compressed air. The efficiency of the process depends on the pressure of air, nozzle diameter, and the distance from the surface being cleaned to the nozzle, the optimal distance being from 200 to 300 mm. Shotblasting (commonly performed in chambers) effectively cleans out deep and intricately shaped cavities of medium- and large sized castings.

In pneumatic shotblasting installations (Fig. 174) of periodic action castings are cleaned by a jet of blasting shot forced out from a rubber hose nozzle directed at the surface of a casting by the operator.

Castings 15 are delivered on a car 8 into a shotblast cabinet 13 where they are cleaned by fine shot. A jet of compressed air carries the shot from a vessel 11 along a tube 10 and a rubber hose and forces it out through a nozzle 9. After cleaning of the castings, the shot, together with dust, goes into a hopper standing under the car 8. Worm conveyor 7 carries the shot to a sieve 6 which separates it from dust. The shot drops out into a hopper 5 and then into a magnetic separator 4, from which it falls into a bunker 3. The compressed air injected by a blower 1 forces the shot along a pipe 14 into a bunker 12 and then into the shotblast vessel 11. An exhaust fan 19 draws out dust from the magnetic separator into a cyclone 16, from which the dust goes into a bunker 17 and then travels on an elevator 18 into a car 20. Large pieces of waste move on an elevator 2 into a special box.

Airless shotblasting. The process of cleaning takes place at the expense of kinetic energy of the jet of iron shot expelled centrifugally on to castings by wheelabrators, or throwing wheels (Fig. 175).

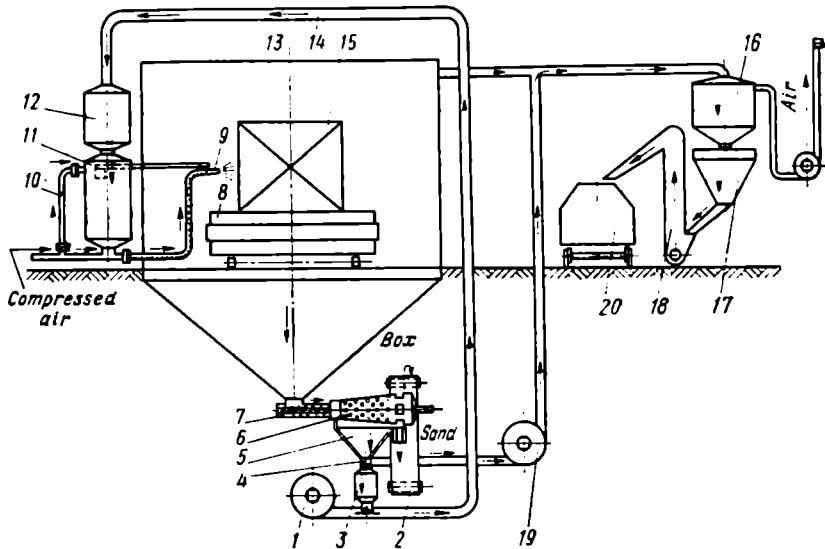


Fig. 174. Pneumatic shotblasting installation

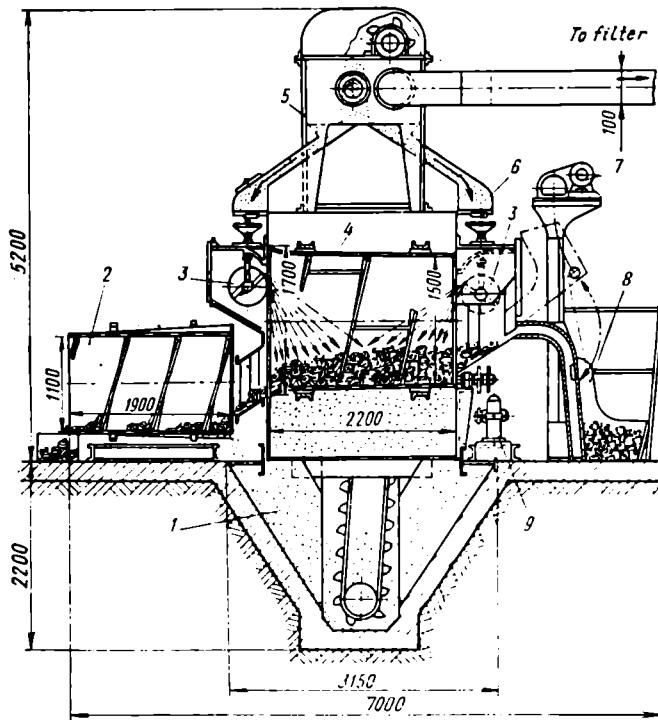


Fig. 175. Airless shotblasting chamber of continuous action

1—cleanout pit for shot and slag; 2—discharge screw conveyor; 3—wheelabrators; 4—tumbling barrel; 5—shot cleaning system; 6—shot conveying troughs; 7—skip lifter drive; 8—castings charging box; 9—barrel drive

The shotblast wheel (rotor) has eight wear-resistant chromium-alloy iron blades radially arranged on the wheel hub between two discs. The wheel rotates at 2 250 rpm.

The shot moves through a sleeve-distributor (impeller) and drops on the wheel blades which accelerate the abrasive material and expel it out at a speed of 80 m/s on to the surface of parts located on the rotary fettling table. The shot thus cleans the parts from the adhered sand and scale.

In comparison with other cleaning units, an airless shot-blast machine offers the following advantages: a high output, 10 times the output of a pneumatic shotblast machine; low power consumption; shot jet speed regulation by changing the rotational speed of the rotor; and better working conditions.

The shortcomings of airless shotblasting are fast wear of rotor blades and poor cleaning of shaped castings with intricate cavities.

Medium-sized castings can be cleaned in drums of periodic action. Castings are shot blasted by a jet of shot expelled by a rotor, while being tumbled on an apron conveyor that forms a drum. These chain shotblast machines (conveyor wheelabrators) can handle castings up to 40 kg in mass at a capacity of 3 to 7 tons of castings per hour.

For cleaning small and medium-sized castings produced in quantities, airless continuous-running shotblast machines (see Fig. 175) make suitable cleaning installations, which can fettle castings of about 25 kg in mass at a capacity of up to 5 t/h.

Airless shotblast rotary fettling tables of continuous and periodic action come handy for dressing small and medium-sized castings 150 to 500 kg in mass. Castings are placed on a rotary table in the chamber and cleaned by jets of shot expelled by wheelabrators. For cleaning large castings up to 70 t in mass, airless shotblasting chambers have a number of throwing wheels, which increase the effectiveness of cleaning. Airless through-type shotblast chambers find use for cleaning mass-produced castings weighing from 50 to 1 300 kg.

Hydroblasting uses the kinetic energy of a jet of water under a pressure of 9.8 to 19.6 MPa (100 to 200 kgf cm⁻²) which peels off the skin of burnt-on sand, breaks down cores and washes away the fragments from casting cavities. Castings are placed on a rotary or stationary table, or on a car inside a chamber. From the monitor, a jet of water directed at the casting surface breaks away the burnt skin of sand and cores and then the stream of water carries the slurry away from the chamber to a sand regeneration unit. The water passes through filters into settlers where it undergoes clarification for repeated use. This method produces no dust, effectively washes out the baked sand from the cavities of medium-sized and large castings, and permits regeneration of sand for reuse. But it consumes much

water, 4 to 25 m³ per ton of castings, involves the use of cumbersome installations of comparatively low productive capacity.

Hydroblasting units can operate on a periodic and a continuous basis. The first are adaptable for cleaning medium-sized and large castings (produced by pieces and in small lots) and the second for fettling batch-produced castings. The productive capacity of water-jet cleaners is 1 to 20 tons of castings per hour, each weighing from 10 kg to 200 t with overall dimensions from 0.2 to 10 m.

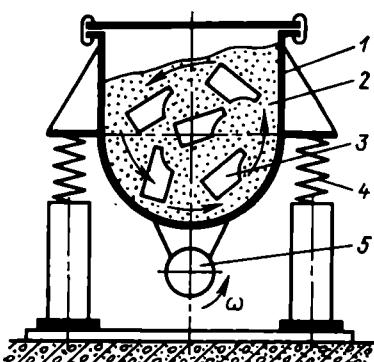


Fig. 176. Principle of a vibrator for cleaning castings
1—chamber; 2—abrasive; 3—castings;
4—spring; 5—drive

particles from the casting surface.

This method effectively cleans the surfaces of aluminum and magnesium alloy castings, where quartz sand and aluminum grains (grit) act as abrasives.

After hydroblast abrasive cleaning, the castings are washed off and treated with an anticorrosion solution that prevents the metal surface from oxidation.

Vibratory cleaning. The castings destined for cleaning are loaded into a vessel (Fig. 176) together with a treating medium—pieces of abrasive (sand, shot or grit). The tightly closed vessel is put into vibratory motion at a frequency of vibrations up to 3 000 a minute. In the process of vibration the abrasive particles tear off the baked sand and clean the casting surface. The choice of the type of abrasive depends on the shape, size, and material of castings, and also on the requirements for the surface being treated.

The abrasives used for cleaning of castings are mostly tumbling stars or picks (star-shaped grains of chilled cast iron, called steel abrasives) or scrap of abrasive cutoff wheels bonded with bakelite or a ceramic material.

Vibratory wet-type abrasive cleaning. The abrasive medium here is

Hydroblast abrasive cleaning. This wet-type fettling method uses a cleaning suspension that consists of the grains of quartz sand, synthetic corundum, metal grit, water, and a surfactant (up to 1%). An ejector throws out an abrasive jet of suspension on to the surface of a casting, which grinds the surface and thus cuts off projections and decreases the surface roughness.

The jet of suspension produces a greater effect if it strikes on the surface being treated at an angle of 30 to 60°. A surfactant, such as naphthenate soap, sulfite liquor, or other type penetrates into microfissures and aids in removing foreign

a suspension of an abrasiv material in an acid, neutral, or an alkali solution. Acid solutions are useful for cleaning castings from oxide films; neutral solutions act as intermediaries, when passing from one stage of the process to the other; and alkali solutions make for removing adhered sand, fins, flash, and for rounding off sharp edges. To prevent castings from corrosion, solutions are mixed with various passivating additives, for example, calcined soda.

Wet-type fettling plants use 2 to 5-% aqueous solutions of alkalis (KOH and NaOH), which increase the productivity 1.5 times in comparison with the dry method, for cleaning iron and steel castings; 1-% solution of calcined soda in water makes a cleaning medium and 1-% solution of chromic anhydride in water with 0.3% sodium chloride acts as a surface finishing medium for brass and bronze castings; and 1-% solution of trisodium phosphate in water is suitable for cleaning casting made from aluminum, magnesium, and zinc alloys.

5.4. CHIPPING AND GRINDING OF CASTINGS

For chipping the flash from castings at the places inaccessible for snagging, it is usual to use pneumatic chipping hammers with a short stroke, up to 100 mm, when trimming small castings, and with a long stroke, for finishing large castings. The efficiency of a hammer largely depends on the chosen shape of a chisel. Chisels made from tool steels are most durable. The chisel tip should have a hardness of 58 to 61 HRC. Electric power-driven hammers have recently come into use for chipping and trimming steel castings.

Wheel grinding of castings. The exposed surfaces of castings are ground or snagged to remove flash, fins, correct the shift in the casting plane, and make the surface even. The abrasive wheels used for grinding are made with ceramic, bakelite and vulcanite binders. Snagging of castings may be done on flexible shaft grinders, swing frame grinders, floor stands, and automatic and semiautomatic machines.

Flexible shaft grinders snag the planes and trim off the faces of castings after cutting or chipping small stumps of gates, fins, and pads. Swing frame grinders give a rough surface finish to large and medium-sized castings produced on a mass scale.

Floor stands are stationary rough grinding machines which snag off the stubs of gates, pads, and fins. During grinding, the castings are pressed against the rotating abrasive wheel by hand or by a special fixture. The wheel hood has water-filled sump attached at its bottom to collect dust and thus decrease the pollution of air in the shop.

Automatic and semiautomatic rough grinding machines find use in mass production of castings. Semiautomatic grinders are high-run

machines which increase the labor productivity manifold, especially when grinding small castings. The work of semiautomatic grinders requires breaking down castings into groups according to the location of surfaces being treated and the shape and size of the surfaces. Besides, semiautomatic machines must be complete with appliances for fastening and feeding the castings to the machines and removing the castings after grinding.

Painting of castings. This operation is necessary to protect castings from corrosion during storage prior to machining. Gray and malleable iron castings are given one coat of nitrocellulose enamel. Before painting, the castings are washed off in a two-chamber unit with a 0.5-% soda solution at 80-85°C for 1 min and then in a stream of hot water of the same temperature. Next the castings are dried by hot air for 2 min and cooled in the air for 5-7 min. The coat of enamel is applied by spraying or dipping into a bath. The castings are then dried in a chamber at 60°C for 10 min.

5.5. HEAT TREATMENT OF IRON CASTINGS

The purposes of heat treatment are diverse; namely, to relieve the casting stresses, stabilize dimensions, reduce hardness, improve workability, impart desired mechanical properties, and raise the durability of iron castings. There are various types of heat treatment given to iron castings.

Stabilizing. This is a stress-relief annealing operation performed at temperatures which depend on the chemical composition of iron. For castings from gray iron, high-strength iron, low-alloy iron, and high-alloy iron, stress relieving usually involves the heating to 500-700°C, 550-650°C, 570-600°C, and 600-650°C, respectively, and then holding (soaking) at these temperatures for 3 to 10 hours depending on the mass and shape of the castings. Intricately shaped castings and castings with walls of various thicknesses require a longer time of holding. After holding for a certain length of time the castings are allowed to cool down in the furnace. This type of heat treatment does not practically change the mechanical properties of castings.

Graphitizing. This annealing treatment is commonly aimed at reducing the hardness and improving the machinability of castings. The process of heating in the furnace to 680-750°C followed by slow cooling results in graphitizing and partial spheroidizing of eutectoid cementite. This heat treatment improves the above properties, but reduces somewhat the strength of cast iron.

Homogenizing is a high-temperature annealing aimed at graphitizing primary carbides in chilled cast iron and in mottled pig iron. The operation consists in heating of castings to 900-960°C and then slow cooling to 300°C. The homogenization treatment produces a pearlitic structure of optimal hardness and strength.

Normalizing increases the mechanical properties and wear resistance of cast iron as it improves its structure and produces a pearlitic metal base. The normalizing treatment is also performed on castings with a ferritic, ferrite-pearlite, or ledeburite-pearlite structure. The heating temperature for this process ranges from 850 to 950°C. During the normalizing treatment of ferritic and ferrite-pearlite irons, a portion of ferrite dissolves in austenite, with the result that the quantity of combined carbon grows.

Normalizing of chilled cast iron causes graphitizing of primary carbides. After cooling in the air to 500°C, the castings obtain a pearlitic structure; starting from 500°C, the castings need slow cooling in the furnace to relieve stresses.

Hardening and tempering. Hardening is a heating and quenching process applied to castings made from gray, high-strength, and malleable irons for the purpose of raising the strength, hardness, and durability. The process consists in heating the castings to 880-930°C and quenching in oil to obtain a martensitic structure. Tempering is the process of heating the hardened castings to 400-600° with subsequent slow cooling. Castings destined for friction service are tempered from 250-300°C. Spheroidal graphite iron castings called for work under friction conditions are subjected to austempering (the resultant structure is called bainite).

Chemical heat treatment is usually employed to impart high surface strength to spheroidal graphite iron castings (I.C.E. sleeves, crankshafts, and others).

Chapter 6. CASTING DEFECTS

6.1. GENERAL

Any irregularities in the production process are likely to cause defects in castings. Defective castings, even at advanced foundries, account for 2-5%, and sometimes for 10-20%, of the number of produced castings. Foundries have special waste sites to which shops deliver the rejects every day. The foremen, technologists, and workers directly responsible for the spoilage thoroughly examine scrapped castings on the site, determine the possible causes, take preventive measures, and analyze the accomplishment of the tasks set previously for minimizing the waste. All foundries take technological and organizational actions with the aim to investigate the causes of basic types of spoilage and work out the methods for its elimination.

Classification of casting defects. The defects that most commonly occur in castings may be classified under four groups:

- (1) surface defects, which are visible imperfections on the surface of castings, such as an incorrect shape and mass, laps, flashes, and so on;
- (2) internal defects and discontinuities of material, such as hot and cold cracks, blowholes, and others;
- (3) incorrect chemical composition and defective structure of castings;
- (4) unsatisfactory mechanical properties.

6.2. TYPES AND CAUSES OF DEFECTS. PREVENTIVE MEASURES

Inaccuracy of dimensions of a casting relative to the drawing dimensions may result from the incorrectly specified metal shrinkage being allowed for in the making of the pattern and also from the inaccurate assembling of the mold. The defect can be remedied by bringing up the pattern to size and correctly closing the mold.

Inaccuracy of the mass of a casting relative to the mass specified in the drawing most often arises from the same causes as the ones which lead to the incorrect shape or dimensional inaccuracy. Swelling of the casting due to deformation of the mold being poured with molten metal may also be the cause of the increased mass.

Lap and misrun (Fig. 177) result from an incomplete union of two streams of metal that has lost the required fluidity before filling completely the mold cavity. Such streams appear when an insuffi-

ciently overheated metal is poured into the mold through the gates

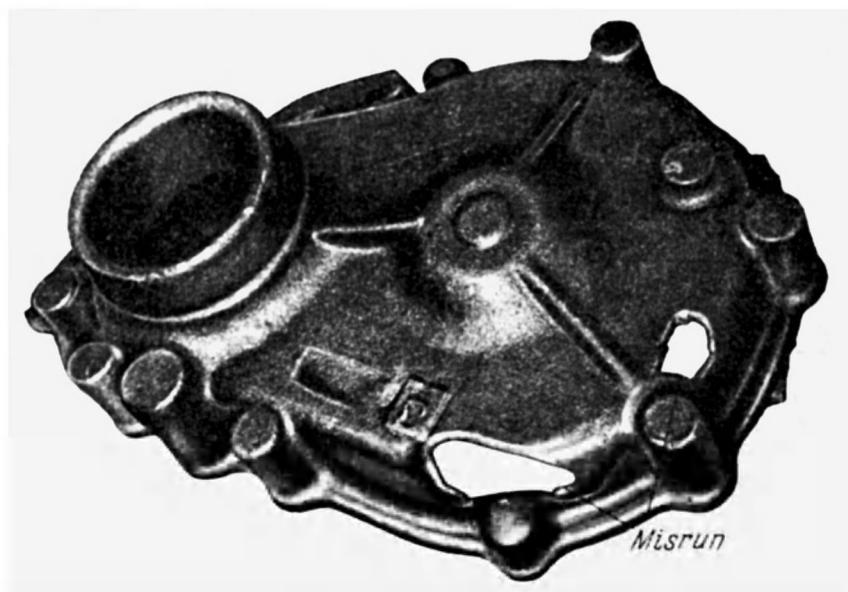


Fig. 177. Misrun casting

of a small cross section. Other causes are due to an excessively moist sand (when running thin-walled castings) and to a large sea coal content of the molding sand.

Flashes, or fins, commonly appear along the mold joint at the places where the mold halves do not fit together properly because of much wear or warping of flask halves, or improper fastening of the cope to the drag.

Mismatch is a shift of the individual parts of a casting with respect to each other. The defect results from an inexpert assembling of the mold (from the cross-joint and poor centering of mold halves), from wear of pin bushes and pins, and dimensional discrepancy between the core prints of the pattern and the core prints of the core.

Metal penetration, or burnt-on sand, that is, a strong crust of fused sand on the surface of a casting, results from insufficient refractoriness of molding materials, a large content of impurities, inadequate mold packing and poor quality of mold washes. Fig. 142 shows the casting with a large sintered layer of sand.

Rat tails are long, branch-like cavities with a crust of metal separated from the casting body by an interlayer of molding sand. They usually form on flat and large surfaces of a casting in a strongly

packed green-sand mold. Rat tails (Fig. 178) result from the thermal effect of liquid metal on the mold walls which heavily deform under heat, causing a depression in the casting surface. The mold wall sometimes deforms so strongly that the surface skin of the mold can spall off, forming a crack into which the melt enters quite readily.

To remedy the defect, it is necessary to reduce mold hardness, pour the melt of specified temperature into the mold at an increased rate, and use special washes which exclude the formation of cracks under the heat of metal. Rat tails can be eliminated by carving narrow grooves (in the form of a network of criss-crossed lines) with a slicker on the mold surface, or providing special ribs on the pattern. These grooves decrease the deformation of the surface layer and thus reduce spalling.

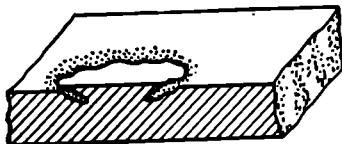


Fig. 178. Rat tails on the surface of a casting

Hot cracks are hot tears which appear in the form of irregular crevices with a dark oxidized fracture surface. They arise from an excessively high temperature of casting metal, increased metal contraction, incorrect design of the gating system and the casting on the whole, poor deformability of cores, and nonuniform cooling which gives rise to internal stresses. A deviation of the chemical composition of metal from the analysis is also one of the causes of hot cracks.

Cold cracks appear as narrow fissures with light metallic luster free of oxide spots. They result from nonuniform contraction of individual portions of the casting and, sometimes, from improper handling of castings during shakeout and fettling operations, causing mechanical damage. The practical ways of remedying the condition consist of making provisions for uniform solidification of thin and thick sections.

Gas cavities are semispheroidal or spheroidal voids having a clean and smooth surface. They appear either on the casting surface (open cavities), or in the body of a casting (closed cavities). These defects are due to an excessive gas evolution and inadequate gas permeability of molding sand, poor venting of the mold and cores or incorrect location of vents, low pouring temperature, insufficient drying of the mold and cores, high gas content of the metal, and incorrect feeding of the casting. Revealing the causes help remedy the condition.

Figure 179a shows blows resulting from excessively moist molding sand, and Fig. 179b blowholes revealed after treatment.

Drop (crush) in a mold is a defect caused by the breakaway of a part of molding sand as a result of weak packing of the mold, low

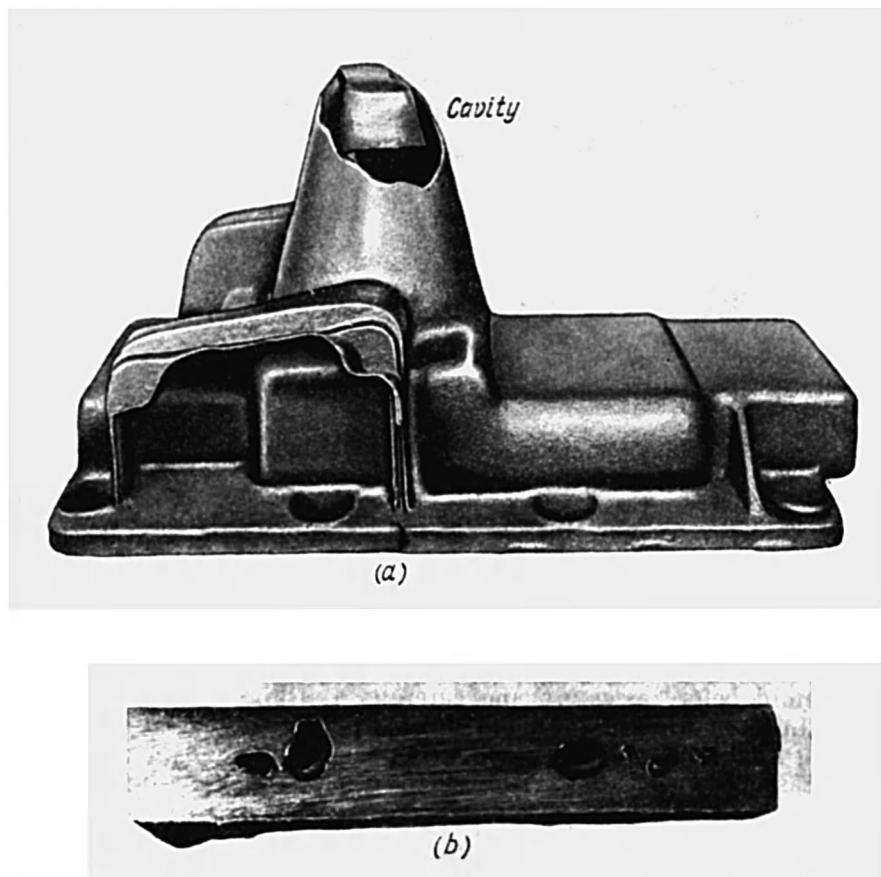


Fig. 179. Gas cavities in castings
(a) blow; (b) blowhole

strength of molding sand, malfunction of molding equipment, strong jolts and strikes at the flask when assembling the mold. Fig. 180 illustrates a characteristic defect in the casting due to a drop in the mold.

Sand holes show up as large irregular cavities on the surface of a casting. This defect arises from a low strength and moisture content of molding sand, insufficient surface strength of the core, weak ramming, and inadequate blowing-off of the mold cavity before assembling the mold. Another cause is due to the fact that the stream of metal erodes the mold and thus tears away mold pieces and sand grains and carries them along into the casting. It is possible to prevent this condition by properly packing the sand, thoroughly blowing off



Fig. 180. A defect in a casting due to a drop in the mold

the mold before assembly and carefully finishing up the pouring cup. Long holding of the mold before pouring should be avoided.

Slag inclusions may appear both on the surface and in the bulk of a casting. These are cavities partially or completely filled with

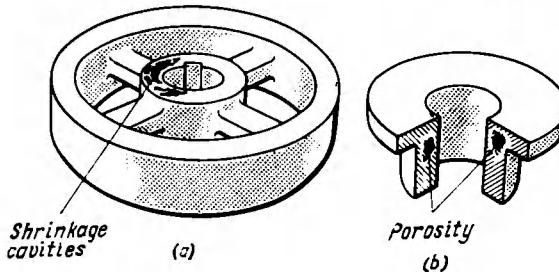


Fig. 181. Castings with shrinkage cavities and shrinkage porosity

slag that gets into the casting when pouring metal into the mold. The slag spots are due to a poor skimming of slag in the ladle, low refractoriness of the ladle lining, and incorrect gating design.

Shrinkage cavities are voids of an irregular shape with a rough, coarse-grained, and mostly oxidized surface (Fig. 181a). They appear

as a result of insufficient feeding of massive members of a casting, poor casting design, incorrect arrangement of gates and risers, pouring of too hot metal into molds, and increased shrinkage.

Pinholes and shrinkage porosity are the defects caused by poor feeding of a casting in the process of its crystallization (Fig. 181b). They also appear in thick sections of a casting. Local porosity can be prevented by installing chills in thick sections, changing the casting design, and levelling the thickness of walls.

Inaccuracy of the chemical composition of metal against the specified composition may arise from an incorrect proportioning of charge materials, blending of various kinds of metal, and poor melting practice. It is only possible to remedy the condition by properly checking the quality of starting materials, strictly observing the sequence of weighing and charging the materials, and exercising strict control over the furnace run.

Unsatisfactory mechanical properties of a casting commonly arise from an inadequate chemical composition and structure of the metal being poured.

6.3. INSPECTION

Visual inspection of castings can reveal many of the common surface defects. The procedure is carried out in two steps, prior to cleaning and annealing and then after the final fettling operation.

The chemical composition of castings is assessed by the methods of chemical and spectral analysis. Test pieces being used for this type of analysis are commonly cast-on test bars (cast integral with the casting) or separately cast test specimens prepared for testing strength properties.

In the spectral analysis, the light of sparks or an arc struck between the electrode and the sample under test falls on an optical prism which disperses it into a spectrum of color bands characteristic of the chemical composition of the metal. This method relies on the comparison between the spectrum of the metal under analysis and the spectrum of a standard specimen. Comparing the intensity of spectral lines (indicative of the content of this element or the other) in the spectrum of the standard and in the spectrum of the test specimen, we can judge of the content of a given element in the casting. The basic advantage of this method lies in rapid evaluation of the contents of manganese, chromium, nickel, silicon, and other elements.

Geometric dimensions of castings are checked with templates, special appliances, and marked-out plates. The deviations of dimensions should not exceed the permissible limits.

Inspection of the mechanical properties of gray iron castings includes tests in bending, tension, flexure, hardness, and, sometimes, compression made on special test pieces.

Malleable iron castings are subjected to tension, elongation, hardness, and, in some cases, to impact tests; steel castings, to tension, elongation, compression, and hardness tests (done on specimens turned from cast bars); and nonferrous alloy castings, to tension, elongation, and hardness tests.

The metal structure of castings is determined from the macrographic examination of test-bar fractures or microsections (by the naked eye), or from the examination of specimens under a microscope with a 100 to 500 \times magnification.

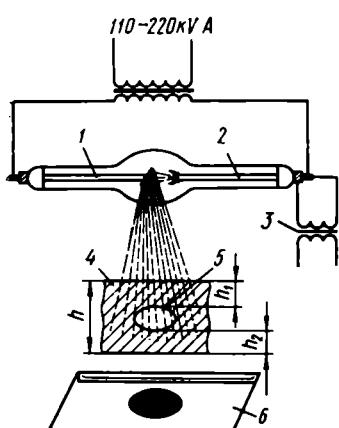


Fig. 182. Radiographing a casting with an X-ray unit

Faults in castings, such as cracks, cavities, and porosity, can be revealed by a magnetic method, radiographic method (exposing test pieces to X-rays or gamma rays), and by a pressure-tightness method.

Magnetic testing. The principle of magnetic testing of castings comes to the following. First it is necessary to magnetize the casting being tested and place it between the poles of an electromagnet or in the magnetic field of a solenoidal coil. If we now move the energized coil along the casting, and as soon as the coil comes across a defect on its way, the magnetic flux changes its direction and induces an emf in the coil turns, the value of which can be read from the galvanometer.

In magnetic-particle testing, the defects can be detected using iron filling sprinkled on a magnetized casting or a magnetic emulsion spread over its surface (the test methods being called the dry and the wet method respectively). Small castings are sometimes immersed into the bath of a magnetic emulsion. The magnetic powder or dust applied to the casting surface piles up at the place of a hidden flaw and outlines its area.

X-ray inspection. This nondestructive method of testing uses special X-ray machines (Fig. 182). The basic element of these units is an X-ray vacuum tube, which is a glass vessel evacuated to 10^{-6} - 10^{-7} mm Hg with electrodes 1 and 2 connected to a high-voltage source (110-120 kV A). As a filament transformer 3 heats up the cathode, electrons break away from this electrode under the action of the applied electric field and head for the anode where they cause vibrations of electrons on the inner atomic orbits. These vibrations of electrons give rise to short electromagnetic waves, called roentgen rays, directed from the anode on to a casting 4 being examined. Volume discontinuities 5, such as cracks, voids, and microporosities,

decrease the actual thickness of the casting body ($h > h_1 + h_2$), with the result that the absorption of the X-ray beam directed through the casting will vary in proportion to the thickness of the different parts of the casting. The sections with cavities or cracks will absorb a smaller amount of X-rays, so that on the X-plate these defects will appear as a spot (shadow) reproducing the contours of the flaw.

Roentgen rays have an injurious effect on any of the body tissues of man, therefore the operating personnel should strictly follow the safety regulations.

Gamma ray exposures. This type of inspection lends itself to the detection of flaws in heavy-walled castings. The gamma-ray emitting sources are radioactive isotopes. The most common gamma-ray radiography setups operate on the radioactive element Co⁶⁰ which, however, gives adequate radiographs only if the thickness of castings exceeds 30 mm.

Checking of a casting for pressure-tightness, or impermeability, involves water or air-pressure tests. The cavity of a casting is plugged up and held under a certain pressure of water, the test pressure depends on the conditions in which the casting has to operate. The outer surface of the casting must be dry in the hydrostatic testing, otherwise it will be impossible to detect the traces of leaking, if any.

In the air-pressure test, the surface of a casting is coated with a soap solution. If the casting is permeable, the bubbles appearing on its surface will show the place of leakage.

6.4. SALVAGING OPERATIONS

Minor flaws on the unimportant surfaces of a casting can be corrected. The methods used for rectifying the defects in iron castings include electric welding, metal spraying, gas welding, luting, impregnating with various compositions, and others.

Cold welding is an arc welding method for remedying the defects with the aid of various filler materials, such as steel, copper, steel-sheathed copper, copper-nickel electrodes, and special filler rods. Defective areas to be welded up are grooved with pneumatic chippers or drilled out.

The cavity correctly prepared for welding should have the shape of a cup with gently sloping walls tilted at an angle of 35-40° to an open-cut bottom. Cracks should be cut out to the entire depth. Iron is inferior to steel in weldability as it has higher brittleness, enhanced response to the rate of cooling, and sharply passes from the solid to the liquid state, and vice versa. The portion being welded up will have an inhomogeneous structure because of nonuniform heating. Poor-quality welding can cause the formation of cracks and other defects in the weld and in the base metal.

Welding with preheating is another ferrous-electrode arc welding method for correcting the defects (large cavities, holes, and cracks) on the iron casting surfaces to be machined. Before being welded, the castings are heated to 600-650°C (to dark-red color). Large castings are preheated in special pits dug out in the sand floor. The bottom of such a pit is first covered with glowing coal and then the casting to be repaired is placed on the coal bed. The castings laid in the pits are heated very slowly, for 1/4 or 15 h. The heating temperature is measured with a contact thermocouple. The repaired spot is coated with glowing coke and the casting is left to cool slowly to exclude chilling in the weld.

Metal spraying is used to decrease porosity in gray iron castings after the welding operation. The weld is cleaned and then coated with metal 0.3 to 0.8 mm in thickness by a special apparatus, called the metal spray gun, which gives a coat of metal 0.03 mm thick in one pass.

The process of metal spraying consists in blowing out small drops of electric-arc melted metal by the compressed air on to the casting portion that requires repairing.

Gas welding with preheating is a suitable method for correcting the defects in gray iron castings of complex configuration, whose sections sharply vary in thickness. The method of welding ensures a high strength and density of the weld seam and also provides for the homogeneity of the chemical composition and mechanical properties of the base and the added metal. Before welding, a casting is preheated to 700°C to preclude the appearance of cracks, stresses and chilling of the casting metal.

The filler rods used here are ferrous electrodes 5 or 6 mm in diameter. The rods must be dense, void of cavities and slag inclusions. The filler material and the place to be welded up is heated by the flame of oxyacetylene or any other suitable gas (hydrogen, vapors of gasoline or kerosene). After welding, the castings are annealed at 450-500°C to relieve stresses.

Welding of bronze castings is effected with a gas torch. The filler material used here is a bronze rod with additions of aluminum, phosphorus, and manganese, which act as deoxidizers. The flux consists of 68% sodium tetraborate, 10% boric acid, 2% charcoal, and 20% sodium chloride. After welding, the bronze castings are heated to 550-600°C and then rapidly cooled to improve the structure.

Welding of aluminum castings necessitates a reducing flame since aluminum is subject to strong oxidation. To decrease oxidation and dissolution of the high-melting oxide, Al_2O_3 , it is usual to use fluxes of the following composition: 15% LiCl, 7% KF, 3% Na_2SO_4 , 30% NaCl, and 45% KCl.

Before welding, aluminum castings require preheating to 400°C to relieve internal stresses. Aluminum rods consisting of 99% or

92% Al and 8% Cu serve as a welding filler. After welding, the aluminum castings are heated to 350°C to relieve stresses.

Luting and impregnation. Lutes, or putties, are plastic substances prepared, for instance, from epoxy resins for smoothing out surface imperfections on castings and improving the appearance of the finish. After sealing of the defective spot with a lute and its solidification, the repaired area is trimmed and the casting is made ready for machining. The solidified lute is a substance of high strength, which readily machines and lends itself to grinding.

Impregnation imparts the desired pressure-tightness to iron castings. The impregnants used for the purpose are a solution of ammonium chloride, ferrous chloride with iron minium and sodium nitrate, a solution of acid carbonate applied at a pressure of 39.2×10^4 - 49×10^4 Pa (4-5 kgf cm⁻²), and phenol formaldehyde lacquer used at a pressure of 98×10^4 - 294×10^4 Pa (10-30 kgf cm⁻²). The use of the latter impregnant is most widespread; after heating to 200°C and slow solidification, this lacquer becomes impervious to water, gasoline, and oil. After impregnation, the castings are dried in the air for 2 or 3 h.

6.5. PRODUCT QUALITY CONTROL MANAGEMENT

The term 'quality' can be defined as the degree to which the product in use will meet the requirements of the customer. An improved quality, increased service life and reliability of products enable the industry to effect savings in raw materials, energy, rationally use labor, and thus increase the effectiveness of production.

Quality control is a system of quality management integrating the efforts of quality control groups at a given plant, which exercise control over the product design, production process, machinery, product testing, inspection and acceptance of incoming materials and contract items, maintenance and repair.

A quality-control program depends on the specific features of a plant. It may include such basic quality-control components as investigation into the customer's quality preferences so as to build the required quality into the product; special studies aimed at developing processing techniques securing the products of improved quality characteristics; process product control; procurement control; product grade certification effected through various types of control (incoming, production, running, in-process, and other types); upgrading of the skill of personnel; moral encouragement and material incentives; and elaboration of the plant's product quality control standards.

So, quality control enters into all the phases of the production process, starting with the development of a product in the design

office through shipment of the product to the customer and ending with its installation and field service.

The functions of quality control divisions. The quality control system of a plant comprises various quality departments responsible for particular quality jobs. The integrated effort is aimed at the manufacture of products that meet the expectations of the customer.

The basic task of these functional groups is of course to exercise control over the quality of products according to the quality standards set for the purpose. The functions of these groups, for example, at a foundry are as follows: (1) quality control of incoming materials and contract items, which includes inspection and testing on the basis of which the customer can accept the materials or lay claims to the supplier; (2) in-process product control and inspection quality control of the foundry products; (3) control equipment supervision; (4) development and improvement of control engineering documentation; (5) production process control, process accuracy checks, performance control of manufacturing facilities, production procedure control, and molding equipment quality control; (6) planning of administrative and technical measures with a view to improving the quality of products and control over the timely realization of the plans; and (7) evaluation of the product quality level.

Organization of quality control. Quality control at a foundry begins with *incoming material control* which involves inspection and testing of charge and molding materials in the foundry laboratory. Metallic materials are checked for the contents of base elements, admixtures, nonmetallic inclusions. Molding sands are inspected for a moisture content, clay content, grain size, and so on. The properties of clay, binders, and molding additives require checking for compliance with the specifications on the molding and core sands. The test results underlie the decision to be made on the quality of purchased materials. If the material has withstood the tests, the certificate is issued for its acceptance and use in the production process.

In-process product control is the control over the quality of a product at all the process stages, that is, in all the shops.

On putting into service new pattern plates, core boxes, or repaired items, a quality control group initiates a complete marking-out of the entire batch of castings produced by the new molding equipment. The satisfactory report of the quality control manager gives permission to employ the new equipment for the production of molds.

The process of preparation of molding and core sands necessitates continuous control over the dry and the green strength, gas permeability, and moisture content. For molding sands, this type of control also involves evaluation of the content of dust, clay and organic substances (constituting the loss in calcination), which affect the plasticity, gas permeability, and gas evolution ability of sands.

If any of the above parameters goes beyond the permissible limits, the sand properties have to be restored by adjusting the sand composition.

In melting cast iron, control over its chemical composition is a routine procedure.

The temperature of iron in melting furnaces is controlled by an optical pyrometer or immersion thermocouple with a recorder. Control over the pouring temperature starts with the measurement of the temperature of metal tapped from the distributor furnace into the first ladle and then into every second or fifth ladle (for important castings, every ladle has to pass temperature control). If the pouring temperature is below the preset value, the ladle should be returned to the melting shop and the metal poured into the furnace to heat it to the desired temperature. If the pouring temperature is higher than necessary, the metal should be held in the ladle for some time to cool it.

The quality of gray iron and high-strength iron is verified by resorting to a chill test that consists of casting a wedge-shaped specimen and comparing visually its fracture with the fracture of standard specimens. High-strength iron is checked for the shape of spheroidal graphite and the ratio between the pearlitic and ferritic constituents; the microstructure is determined by the analysis of a sample taken from the ladle.

Test specimens cut from cast bars are used for testing strength properties of iron.

It is the task of a quality inspector to check the temperature of metal in the ladle, take samples for chemical analysis, microstructure and fracture examination, and for analysis of mechanical properties. He enters all the results in the log.

Inspection quality control of castings consists of complete and choice types of control. The first type is essential for critical castings, and the second for less important castings. If the inspector detects a critical defect (a cavity, crack, or nonmetallic inclusion) even in one of the castings while exercising choice control, he must subject the whole lot of castings to complete control.

Sound castings are transported to the store with a quality certificate testifying the acceptance.

Statistical quality control methods find now increasing uses in foundry shops.

Part IV

PRODUCTION OF MALLEABLE CASTINGS

Chapter 1. MOLDING PRACTICE AND MELTING

1.1. GENERAL

Malleable (cast) iron has a great many applications as a structural material in automotive-tractor, agricultural machinery, and other industries. This iron is an annealed white cast iron. Annealing decreases hardness and improves ductility and machinability of castings. The process of annealing causes graphitization in white cast iron, that is, liberation of graphite of compact form, with the result that the iron acquires improved mechanical properties. In comparison with gray cast iron, malleable iron has better mechanical properties (Table 54) and greater percentage elongation (also called specific

Table 54
Classification of Malleable Cast Iron

Grade	Rupture strength, MPa (kgf mm ⁻²)	Elongation, %	BH, MPa (kgf mm ⁻²)	Grade	Rupture strength, MPa (kgf mm ⁻²)	Elongation, %	BH, MPa (kgf mm ⁻²)
КЧ 30-6	294 (30)	6	1 600 (163)	КЧ 50-4	490 (50)	4	2 360 (241)
КЧ 33-8	324 (33)	8	1 600 (163)	КЧ 56-4	550 (56)	4	2 640 (269)
КЧ 35-10	344 (35)	10	1 600 (163)	КЧ 60-3	590 (60)	3	2 640 (269)
КЧ 37-12	363 (37)	12	1 600 (163)	КЧ 63-2	620 (63)	2	2 640 (269)
КЧ 45-6	440 (45)	6	2 360 (241)				

elongation, or, simply, elongation), for which reason it is often more advantageous to produce shaped thin-walled castings from malleable iron than from steel. A prolonged cycle of annealing, however, puts it at a disadvantage.

In use are two types of malleable iron: ferritic (blackheart) and pearlitic (whiteheart).

Ferritic cast iron, or blackheart (black-cored) malleable cast iron, shows a velvety fracture and a thin white fringe. The microstructure of heat-treated blackheart malleable iron consists of star- or spider-like clusters of temper carbon (nodular graphite) and ferrite. The

rupture strength of this iron is 294 to 363 MPa (30 to 37 kgf mm⁻²), elongation 6 to 12%, and BH 1 500 to 1 600 MPa (149 to 163).

The structure of ferritic malleable iron may contain 10 to 15% pearlite. Such iron features high impact strength and thus makes a highly suitable material for parts operating under dynamic load.

Pearlitic malleable cast iron. This type of iron basically consists of pearlite and clusters of temper carbon. It is produced by subjecting white cast iron or ferritic malleable iron to heat treatment or by adding carbide-forming elements to the iron.

Depending on the composition of the initial white cast iron and the annealing procedure, the rupture strength of pearlitic malleable iron may vary from 490 to 688 MPa (50 to 70 kgf mm⁻²), and elongation from 2 to 5%.

Pearlitic malleable iron may have a pearlite-ferrite and a pearlite structure. The pearlite structure may consist of lamellar, sorbitic, or globular pearlite.

Spheroidal cementite malleable cast iron. The structure of pearlitic spheroidal cementite malleable iron differs from the structure of common pearlitic malleable iron in that it has spheroids, or globules, of cementite uniformly distributed in ferrite. The size and number of spheroids depend on the prior structure of iron and the conditions of spheroidization.

This type of iron is produced from white cast iron rich in manganese (0.7 to 1.2%) through a special heat-treatment procedure. The process consists in prolonged annealing of white iron at temperature below the critical limit (690-670°C) to convert lamellar pearlite to globular pearlite (also called divorced pearlite). Iron produced by the spheroidizing process vary in properties depending on the manganese content, temperature, and time of annealing. The rupture strength lies in the region between 470 and 688 MPa (48 and 70 kgf mm⁻²), elongation 6 and 12%, and BH 1 760 and 2 160 MPa (179 and 220).

Pearlitic irons go into production of castings intended to operate mainly under friction conditions.

The choice of the chemical composition of iron depends on the requirements for physicomechanical and casting properties and also on the wall thickness of castings, melting units, starting materials, and heat-treatment techniques. Table 55 lists the percentages of basic elements of prior white iron used for the production of malleable iron.

Casting properties of white iron. In the production of malleable castings, it is necessary to take account of the casting properties of white iron. Unlike gray iron, white iron used for the production of malleable iron contains much less silicon and carbon, shows lower fluidity, higher shrinkage (1.6 to 1.9%), and greater susceptibility to the formation of hot and cold cracks. Castings experience high internal stresses as they solidify.

Table 55
Chemical Composition of White Iron

C	Si	Mn	S	P	Cr
			not over		
2.50-2.75	1.00-1.20	0.40-0.45	0.12	0.1	0.06

The casting properties of this iron have a bearing on the choice of the casting process: thick members of castings need bobs (risers) and chills to guard against the formation of shrinkage cavities and porosity. Annealing causes warping of many of the castings so that they require press straightening after fettling. Castings from white iron are cleaned twice, before and after annealing.

1.2. SOME FEATURES OF MOLDING PRACTICE

Molds for malleable castings are made on molding machines and automatic molding lines because malleable iron is mainly employed for castings produced on a mass scale.

White iron shrinks more heavily than gray iron, therefore white iron castings have more shrinkage cavities and microporosities. Consequently, in choosing the position of a casting in the mold, one must see to it that the design of the gating system enables progressive solidification of the casting. To exclude the formation of shrinkage cavities and microporosities, the gating should be such that hot white iron can first run into thick members of the casting (the reverse is true for gray iron). Also, at the places where the iron enters thick sections, one should set up *bobs* (*feedheads*, or *risers*) which solidify last. About one-third the height of the bob should lie in the drag.

A bob should feed a casting member through a short and wide gate and be as close to that member as possible. The gate should have a neck (narrowing) to facilitate separation of the bob from the casting. The cross section of the neck is 65 to 75% of that of the member at the place of feed, and the distance from the neck to the casting member is not over 3 mm. Fig. 183 shows a malleable casting with a feed-head.

The use of chills in a mold, placed at thick sections of the casting to speed up cooling, helps eliminate porosity and cracking. Levelling off the thickness of casting walls, where possible, enables achieving the same result. One more method of eliminating porosity is to provide shrinkage ribs at the places where shrinkage cavities are

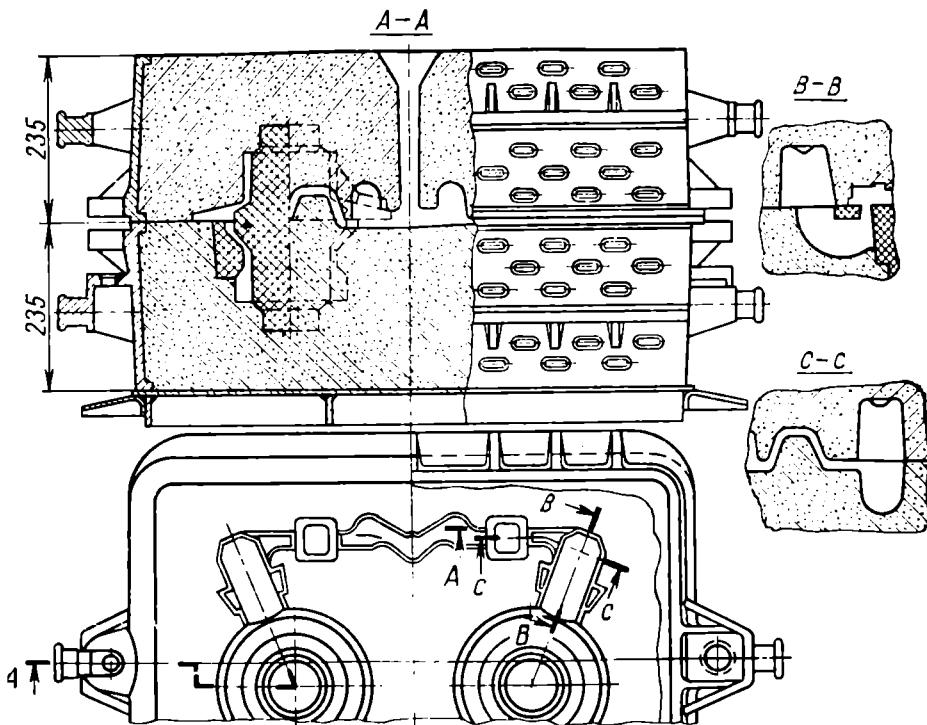


Fig. 183. Casting mold for a car rear wheel hub

likely to form during solidification. The ribs are then cut in the fettling operation.

Castings in which the individual members sharply vary in thickness are left to cool in the molds to sufficiently low temperatures. They cool on conveyors made longer for the purpose, or additionally, prior to stripping the molding sand, on conveyors delivering them to the fettling station. It is also possible to cool hot castings in special pits.

In calculating the gating system for malleable castings, the pouring rate for white iron is taken to be smaller than it is for gray iron because of a lower fluidity of white iron and a larger cross section of gates. The gating system may be calculated by formula (9). The relation between the cross sections of the gate, runner, and the sprue may be taken as $F_g/F_r/F_s = 1/1/1.5$, which differs from that used for gray iron castings. Such a gating system turns out to be filled incompletely and fails to trap slag. To prevent slag from entering the mold cavity, the gating system is provided with a strainer core

(filter core) made of core sands, a choke, or other suitable slag-trapping means. The dimensions of a necked-down riser may be found from the formula proposed by Professor B. V. Rabinovich. First, we calculate the modulus of cooling of the casting

$$L = \frac{V_c}{F}$$

where V_c is the volume of the casting; and F is the casting surface.

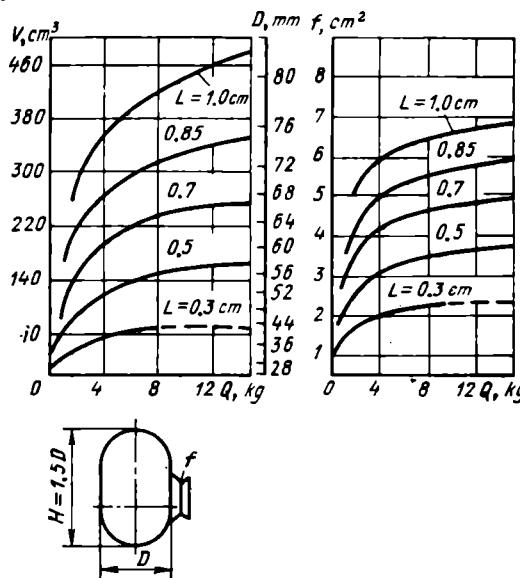


Fig. 184. Diagram for calculating the dimensions of a riser
 V and D —volume and diameter of the riser; f —cross-sectional area of the neck

Knowing the mass of the casting, Q , and the modulus of cooling, L , we can now determine the riser dimensions from the graphs of Fig. 184.

1.3. MELTING WHITE CAST IRON

For production of high-quality malleable iron, white iron should have a low content of carbon and silicon, which determine the structure of the metallic matrix, quantity and form of graphite in the malleable iron.

White iron is melted in a cupola and refined in a suitable furnace. This duplex process can employ a cupola and an electric furnace, a cupola and a reverberatory furnace, a cupola and an induction furnace. Melting of iron in a cupola is the cheapest method, but it cannot provide for a stable production of malleable iron of most

popular grades. The reason is that it is difficult to produce white iron with a low carbon content and high overheat in the cupola.

High-quality white iron with an invariably low content of carbon, high overheat, and, consequently, with good mechanical properties can be produced by a duplex process based on the use of a cupola and an electric acid-lined furnace. Iron is melted in the cupola and then passed to the electric furnace where it is heated to 1 500-1 550°C and refined to the desired chemical composition as regards the content of silicon, manganese, and carbon. High overheat is necessary since it raises iron fluidity and makes up for the heat lost during inoculation. Besides, overheating facilitates separation of slag inclusions and provides for finer graphite, with the result that gases escape from the mold more readily and castings require less time for annealing.

Production of iron with 2.6-2.9% C in common cupolas poses a difficult task. For this it is necessary to use receiver cupolas, arrange tuyeres at a height of 150-100 mm from the cupola hearth, introduce 40-45% steel scrap into the charge, ensure a blast intensity of 130-140 m³/(m² min) and an iron temperature in the spout not lower than 1 400-1 420°C. The ratio of Mn to S in the charge must be equal to 3.5:1. Slags must show the highest possible fluidity, which can be achieved by adding, for example, such a fluxing agent as dolomite. The cupola should be run with the slag notch open to enable higher overheat of the iron. If a cupola iron contains about 2.9% C and 0.5 to 0.75% Si, graphite cannot separate out, and the resultant casting has the structure of white iron.

Calculation of the charge for melting white iron. If the charge consists of pig iron, foundry returns and steel scrap, we have to calculate the carbon content of the charge with respect to pig and foundry returns separately because these two charge constituents differ in the content of silicon.

Knowing the carbon content of pig iron and foundry returns from the laboratory analysis, we can determine the carbon content of the liquid iron, $C_{l,tr}$, from the formula

$$C_{l,tr} = aC_{ir} + bC_{st} \quad (22)$$

where a and b are portions of iron and steel in the charge respectively; C_{ir} and C_{st} are the carbon contents of the iron and the steel part of the charge respectively, taking into account the carbon pickup (carburization) during melting.

In determining the degree of carbon pickup by steel, the following relation may be useful

$$C = C_{st} + K + l \quad (23)$$

where K and l are respectively the coefficients of carbon pickup for steel in the coke bed above the tuyeres and in the cupola crucible, %.

The value of C_{st} is found experimentally. The value of K depends on the consumption of coke and air (Table 56).

Table 56

Carbon Pickup Coefficient K Versus Coke Consumption

Coke consumption, % of metal charge	Relative blowing rate, $\text{m}^3/(\text{m}^2 \text{ min})$		
	100-120	140-160	180-200
9	1.3	1.1	0.9
10	1.4	1.2	1
12	1.5	1.3	1.1
15	1.7	1.5	1.3
20	1.9	1.7	1.5

The coefficient l is found from the formula

$$l = \alpha h$$

where α is a coefficient assumed equal to unity for a receiver cupola and to 1.5 for a cupola without the receiver; and h is the height of the cupola crucible, m.

Example. The charge composition includes 30% foundry pig iron (3.7% C), 50% foundry returns (2.8% C), and 20% steel scrap (0.04% C).

The pickup of carbon in the cupola crucible is insignificant because the cupola hearth is rammed almost up to the level of the lowest row of tuyeres. The amount of coke for a coke bed averages 12-14%, the blast intensity is equal to 100-110 $\text{m}^3/(\text{m}^2 \text{ min})$, and K to 1.5 according to Table 56. We find the carbon content from relation (23) in view of formula (22):

$$C_{l,tr} = 0.3 \times 3.7 + 0.5 \times 2.8 + 0.2 (0.04 + 1.6) = 2.84\%$$

To simplify the calculations, we disregard the carbon introduced into the charge with the additions of ferroalloys. So that the liquid iron may contain 2.5-2.6% C, we have to raise the percentage of steel scrap (0.04% C) in the charge to 40%, leave the percentage of pig iron the same, and decrease the amount of foundry returns (2.6% C) to 30%. Using formula (22), we calculate the carbon content of liquid iron:

$$C_{l,tr} = 0.3 \times 3.7 + 0.3 \times 2.8 + 0.4 (0.04 + 1.52) = 2.57\%$$

In the process of iron melting, care should be taken to force the right amount of air into the cupola. With an increased blast input, iron strongly oxidizes and the castings can suffer from such defects as cracks and misruns. The blast intensity (relative blowing rate) depends on the cupola diameter in the fusion (melting) zone. Thus, for a cupola 1 550 mm in diameter, the blast input must be equal to approximately 135 m^3/min per square meter of the cross-sectional area of the melting zone. A decrease in the height of the charge column by more than one batch is impermissible during the heat.

If the cupola has stood idle, with the blast cut off over 30 min, the next heat should begin with the addition of a coke booster consisting of selected coke lumps 40 to 100 mm in size. Slag is discharged from the cupola periodically, every 20 min, care being exercised to keep metal from getting into the slag hole and slag into the taphole. If the sulfur content of iron exceeds the limits (0.1-0.12% and over), one should desulfurize the first 3 or 4 metal batches with calcined soda. After this treatment, the sulfur content of iron drops to 0.06-0.08%. To obtain white iron of the same chemical composition from two cupolas, the metal from each cupola can be tapped into a mixer through the spouts connected to a common trough above the mixer.

The duplex process using a cupola and an electric furnace. Iron is melted in a cold-blast cupola. To produce a cupola iron with 2.6-2.85% C, 0.8-1.1% Si, 0.15-0.25% Mn, about 0.1% S, 0.12-0.17% P, and about 0.06% Cr, the charge should contain 17.6% foundry pig iron, 34% foundry returns, 42.1% steel scrap, and 5.3% blast-furnace ferrosilicon (with 18% Si). The cupola iron flows into a mixer at a temperature of 1 370-1 395°C, from which the ladles convey it into an arc furnace to bring the metal to the desired chemical composition and temperature. The iron tapped from the arc furnace contains 2.5-2.7% C, 0.95-1.15% Si, 0.53-0.6% Mn, about 0.12% S, 0.16-0.18% P, and near 0.06% Si. For thin-walled and small castings, the silicon content may be as high as 1.25% and above. The temperature of iron discharged from the arc furnace comes to 1 460-1 500°C. The iron is first tapped into one-ton capacity ladles from which it is poured into casting ladles.

To lower the carbon content of iron refined in the arc furnace and bring the content of silicon and manganese to the desired level, it is necessary to introduce the following quantities of additives per ton of iron: 25 kg of 45%-ferrosilicon, 25-30 kg of 80%-ferromanganese, 42-43 kg of steel cuttings, and 1-1.5 kg of iron ore.

Before pouring it into molds, the iron is inoculated in casting ladles to accelerate the process of annealing in annealing furnaces and improve its mechanical properties. The inoculants used here are aluminum, bismuth, and boron.

Aluminum is added to iron in small pieces put directly into a ladle before its filling in an amount of about 0.01-0.015% of the iron mass. The aluminum content of iron should not exceed 0.015-0.02%, otherwise lamellar graphite may precipitate as black spots in thick-walled castings, because this element is a graphitizing agent. During inoculation, the iron temperature should be not below 1 400-1 500°C.

Boron has the same effect on graphitization as aluminum. It encourages the formation of graphitic submicroscopic inclusions and speeds up annealing. Boron is added to iron in the form of ferroboron silicon, ferroboron, and boric acid in an amount of 0.002-0.01% of

the mass of iron. With the wall thickness of castings coming up to 15 mm, the optimal quantity of the boron addition should be equal to 0.003-0.005%.

Bismuth is an antigraphitizing agent. Its additions keep graphite from separating in the iron during its solidification. The presence of thousandths of a percent of bismuth in iron has almost no effect on the length of the first and second stages of graphitization in annealing, but this quantity is enough to promote the formation of the white iron structure.

Bismuth is an expensive element, its melting loss totals over 70% of the mass of the additive. For this reason, bismuth is sometimes replaced by antimony which acts in the same manner as bismuth, dissolves well in iron, and does not practically undergo oxidation.

For treating iron with a complex inoculant (consisting of bismuth, boron, and aluminum), all the constituents are poured into a paper bag (or compressed into a briquette) and then the bag is dropped into a laddle being filled with molten iron.

The duplex process using a cupola and a core induction furnace. The iron melted in the cupola has the following composition: 2.75-2.86% C, 0.95-1.3% Si, 0.25-0.4% Mn, 0.16-0.2% S, 0.15-0.16% P, and 0.05-0.06% Cr. The temperature of iron tapped from the cupola is 1 380-1 400°C. The iron is poured into ladles which then charge it into a core induction furnace operating on the current of commercial frequency.

It is impermissible to put additives (ferroalloys, iron ore, steel scrap, and others) into the core induction furnace or through its siphon for the purpose of bringing the iron to the desired composition. Ferroalloys can be introduced, if the need arises, in the course of the heat directly into the ladle being filled with iron from the cupola. After dissolution of the additive and slagging-off, the iron is poured into the core induction furnace. One must see that the slag does not get into the furnace. The slag should be raked off directly into the pit near the cupola or soon after filling the ladle with iron from the mixer. If the layer of slag that forms in the furnace begins to cover up the iron surface within the zone visible through the slag hole, the slag should be tapped off, making sure that the furnace is more than half full of metal.

Slag scull should be removed, whenever it builds up. If a plug of metal and slag forms in the siphon, the temperature of metal in the furnace should be raised to 1 500-1 530°C and held at this level for some time until the plug melts down.

The iron brought to the desired composition and heated to not over 1 500°C is tapped from the core induction furnace into casing ladles. As soon as the ladle is one-eighth full of iron, a bag of complex inoculator (consisting of aluminum, bismuth, and boric acid) is emptied into the iron stream.

The use of core induction furnaces for combined operation with a cupola enables the production of iron of the homogeneous composition.

The duplex process using an electric arc furnace and a coreless induction furnace. The chemical composition of the iron being melted in this process is given in Table 55. The charge consists of foundry returns (about one-fourth the mass per heat), powdered graphite, briquettes of steel scrap, and quicklime. The charge is loaded into the arc furnace in two stages with charging buckets. After melting of the batch introduced into the furnace at the first stage, the furnace is charged to full capacity. As soon as the charge is melted completely and the iron temperature raised to $1\ 470-1\ 500^{\circ}\text{C}$, a metal test is taken for the chemical laboratory, the slag is raked off, and a new slag is built up. The slag basicity must be not less than 1.6. If the need arises to adjust the chemical composition of iron, additions of powdered graphite, ferrosilicon, and ferromanganese are made to the bath, and then the melt is heated to $1\ 550-1\ 570^{\circ}\text{C}$ and transferred into the coreless induction furnace through the trough heated to a dark-red color. After removal of the slag from the surface of the bath, electrode scrap is added to produce a neutral atmosphere. The chemical composition can be corrected anew, if necessary, by introducing the above additives. To make the chemical composition of iron more uniform, the melt is held in the furnace for not less than 20 min at $1\ 520\pm10^{\circ}\text{C}$ and then tapped into a ladle for casting. As the iron starts filling the ladle, bismuth and ferroboron are poured into the metal stream in amounts of 0.01% and 0.0056% respectively. The temperature of iron must be $1\ 470\pm10^{\circ}\text{C}$ before pouring and $1\ 410-1\ 300^{\circ}\text{C}$ by the end of pouring into molds. Before filling the mold, a sample of metal is taken from the ladle for fracture analysis. A wedge-shaped specimen (see Fig. 165) is cast in a green-sand mold and cooled for 8 min. The specimen must show a white fracture. Besides, separate test bar specimens are cast in a mold, which are specially prepared for determining the mechanical properties of the iron.

1.4. FETTLING OF CASTINGS

White iron castings require fettling before and after annealing. The purpose of dressing before annealing is to reveal defects, clean castings from molding sand, take off fins which are difficult to remove after annealing, and flog off gates and risers readily broken away with strikes of a hammer. One must exercise care in flogging since the castings are brittle.

Further fettling stages are the same as in cleaning of common iron castings.

After annealing, the castings are cleaned of scale and molding sand. The remaining portions of gates and risers are removed on special presses, with pneumatic hammers, and on automatic grinders. Straightening of castings is performed after annealing, cleaning, and removal of the stubs of gates and risers. The castings left to stay under a layer of sand before annealing warp little and thus require insignificant or no straightening at all. The castings kept without a coat of sand warp heavily on annealing, and almost all need straightening on special presses.

Chapter 2. ANNEALING OF CASTINGS

2.1. MALLEABLE ANNEALING

After fettling, white iron castings are subjected to annealing in gas-fired, oil-fired, or electric batch-type or continuous furnaces. Annealing gives rise to graphitizing—formation of secondary graphite, called temper carbon, or temper graphite.

White iron is annealed to effect either complete graphitization or graphitization with simultaneous decarburization. The process of full graphitization gives ferritic malleable iron (blackheart, with a black core in a fracture); the process of graphitization with decarburization produces pearlitic malleable iron (whiteheart, with a white core in a fracture). To keep white iron from decarburizing, castings are annealed in sealed boxes in a neutral or oxidizing atmosphere.

The graphitizing process includes three heat-treatment stages, namely, initial, intermediate, and final. The initial stage takes place at 960–1 050°C, the intermediate stage proceeds during cooling to the eutectoid temperature, and the final stage occurs in the eutectoid temperature range or somewhat below it.

The procedure of malleablizing depends in each particular case on the transformation processes which may take place in this type of annealing.

Conversion of white iron into ferritic malleable iron. This process of annealing of castings calls for heat treatment in a neutral medium. Annealing is carried out in batch-type furnaces if the runs are short, or in continuous furnaces and elevator-type electric furnaces if the castings are produced in large lots and on a mass scale. Elevator-type furnaces enjoy wide use in the automotive industry. The temperature in these furnaces can be controlled to an accuracy of $\pm 10^\circ\text{C}$.

The thermal cycle of malleablizing for castings 5 to 10 kg in mass and 10 to 15 mm in wall thickness in elevator-type electric furnaces of 25-ton capacity is shown in Fig. 185. The chemical composition of white iron before annealing is as follows: 2.5–2.75% C, 0.95–

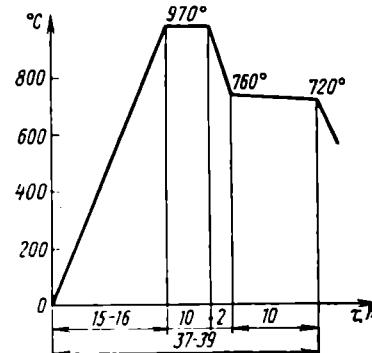


Fig. 185. Thermal cycle for malleablizing iron inoculated with aluminum, bismuth (0.008%), and boron (0.002%)

1.15% Si, 0.35-0.45% Mn, 0.13-0.17% P, about 0.12% S, 0.05-0.06% Cr, and 0.015-0.025% Al. The iron is inoculated with bismuth, boron, and aluminum.

The first-stage annealing involves heating of castings to 950-970°C and prolonged holding at this temperature. In this process, cementite decomposes to form austenite and liberate graphite. The length of heating depends on the furnace design, the mass of the batch (charge), and the mass and wall thickness of castings. The larger the batch mass, the longer the heating period. The time of holding is largely a function of the wall thickness of a casting and its mass. The greater the wall thickness and mass of the casting, the longer the holding period at the first stage of graphitizing.

The second-stage annealing involves cooling below the eutectoid critical limit which lies in the range between 740 and 780°C depending on the iron composition. The process causes conversion of austenite into pearlite and decomposition of cementite that enters the pearlite composition to yield ferrite and free graphitic carbon precipitated in small clusters. The process of malleabilizing intended to convert white iron to ferritic malleable iron lasts 37 to 39 h as seen from the graph of Fig. 185.

The length of annealing depends on the chemical composition and structure of white iron, temperature at the first stage of annealing, furnace design, and on other factors.

Effect of carbon. To produce malleable iron with high mechanical properties, white iron should contain a minimum amount of carbon, normally within the range from 2.2 to 3.2%. A drop in the carbon content below 2.2% impairs the casting properties of white iron, while an increase in the carbon content above 3.2% causes difficulties in the production of this iron, which is especially the case with thick-walled castings. A high carbon content also affects the mechanical properties of malleable iron. The strength and hardness of malleable iron grow with an increased content of combined carbon, while its plasticity decreases. The plastic properties of malleable iron, particularly percentage elongation, mainly depend on the packing density of graphite and the degree of balling-up of graphite precipitates.

Carbon has a little effect on the graphitizing process at its first stage, but strongly influences its course at the second stage—cuts down the time required for the decomposition of eutectoid cementite. The reason is that carbon present in malleable iron causes an increase in the number of graphitizing centers.

Effect of silicon. Silicon dissolves well in austenite. With a rise in the silicon content of iron, the content of carbon in ledeburite, austenite, and pearlite decreases. Silicon exerts an influence on the decomposition of both free and eutectoid cementite and encourages the formation of graphitizing centers. As the content of carbon

in iron grows, the period of annealing shortens, but an excessive amount of carbon results in mottled cast iron or gray cast iron on solidification of castings. When specifying the quantity of silicon in iron, therefore, it is necessary to consider the quantity of other elements that make up the iron composition and the cooling rate of castings (the wall thickness of castings).

In determining the degree of graphitization for common malleable castings, Professor N. G. Girshovich suggests the following formula

$$0.5C + Si = 2.1 \text{ to } 2.5$$

As the carbon content of iron grows, the percentage elongation, necking, and impact strength diminish. The tensile strength does not vary with a silicon content of up to 1%, but then decreases as the silicon content exceeds 1%.

Effect of manganese. As regards iron, manganese exhibits a full mutual solubility both in the liquid and in the solid state, forming manganese carbide, Mn_3C , with carbon. It impedes the process of graphitizing at the first stage and does so even more strongly at the second stage. Manganese should be regarded as an element that hinders graphitization if its content approaches 0.5%.

Effect of sulfur. This element forms a low-melting eutectic, Fe-FeS, and, being practically insoluble in iron, raises the stability of cementite. Sulfur hinders graphitization in the course of annealing as well as during solidification.

In the production of malleable iron, manganese makes a suitable additive to neutralize the harmful effect of sulfur. The required quantity of this additive may be found by the formula

$$\frac{Mn}{S} = 1.7 + \frac{0.3}{S}$$

Effect of phosphorus. This element has almost no effect on the graphitizing process if its content is below 0.18%. Phosphorus reduces the solubility of carbon in ledeburite and lowers the melting temperature of iron. It reacts with ferrite to yield a solid solution of low concentration, and thus has no action on the process of malleable annealing. An increased content of phosphorus impairs the mechanical properties of malleable iron, particularly the impact toughness.

Effect of chromium. This is a carbide-forming element. Chromium retards graphitization as it reacts with carbon, giving stable carbide. Professor N. G. Girshovich considers that it is impossible to produce a ferrite structure in malleable iron with as high as 0.1% Cr because chromium retards graphitization at the first and the second stage and promotes the conditions favoring the formation of globular pearlite. This view is supported by practice, which shows that the chromium content must not exceed 0.06%.

Effect of the prior white iron structure. The finer the structure that has resulted from the iron overheat and rapid cooling of castings, the faster the process of annealing.

Effect of the batch mass. The larger the batch of castings charged into the furnace and the thicker the walls of castings, the slower the process of annealing, and vice versa.

Effect of the heating temperature at the first stage. The higher the heating temperature of iron at the first stage of graphitizing, the

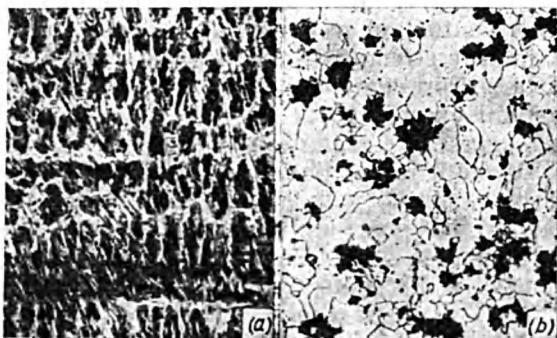


Fig. 186. Microstructure, $\times 200$

(a) white iron before annealing, with cementite-pearlite structure; (b) ferritic malleable iron with ferrite-graphite structure

shorter the process of annealing. But this temperature must be kept below $1\ 000^{\circ}\text{C}$, otherwise castings will warp heavily and entail difficulties in straightening.

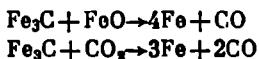
Effect of the annealing furnace design. The furnace design has an influence on the length of annealing. For example, a continuous furnace with a protective atmosphere, which does not require packing of castings in boxes, substantially cuts the annealing time without causing scaling. Fig. 186 illustrates the structures of white iron and ferric malleable iron.

Conversion of white iron into pearlitic malleable iron. On the average, the composition of white iron is as follows: 1.8-3% C, 0.7-1.1% Si, 0.35-1% Mn, not more than 0.18% P, 0.12% S and 0.08 Cr.

After flogging off gates and risers and peeling the burnt-on sand, the castings are put in boxes and covered with iron ore. The boxes are then closed with lids, coated with clay and set in the oven. Annealing in this oxidizing medium involves skin decarburization.

The first stage of annealing consists of heating the castings in the furnace to $950\text{-}1\ 100^{\circ}\text{C}$ and prolonged holding at that temperature (Fig. 187). At this stage of heat treatment, free cementite decomposes, yielding austenite and temper carbon. In the second stage, which

involves cooling, austenite transforms into pearlite, and the iron structure consists of pearlite and temper carbon. After annealing, the content of temper carbon in the iron decreases. In the process of decarburization, the following reactions take place:



Carbon oxide reacts with iron ore to form carbon dioxide. Pearlitic iron shows a silvery fracture. The microstructure of castings

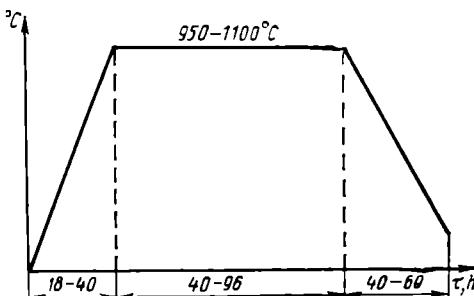


Fig. 187. Thermal cycle of annealing white iron to produce pearlitic malleable iron

across the section sharply varies: the decarburized surface layer has a ferrite structure and the core portion a pearlite-ferrite or a pearlite structure with temper carbon. Pearlitic malleable iron has a smaller percentage elongation than ferritic iron, for which reason it is used for less critical castings such as fittings, nipples, nuts, and others.

Annealed castings are inspected for the macrostructure, mechanical properties, and microstructure. The macrographic examination involves visual examination of the fracture of cast-on test bars broken away from the castings. Ferritic malleable iron must have a black core and a small ferritic fringe in the fracture. The test bars of insufficiently annealed castings show a white fracture. Such castings are subjected to reannealing. Pearlitic malleable iron must have a white heart in the fracture.

The strength properties of malleable iron are evaluated from the tensile tests made on specimens cast in green-sand molds. The test bars measure 16 mm across, 70 mm in gage length, and 190 mm in total length.

2.2. SHORT-CYCLE MALLEABLE ANNEALING

A prolonged period of malleabilizing—a great disadvantage from the mass-production standpoint—has generated a need for developing the accelerated methods of annealing treatment. Short-cycle annealing is largely adaptable to the production of ferritic malleable iron.

Speeding up heating and cooling of castings in the furnace. Box annealing without covering castings with iron ore and open annealing are the two annealing methods which in the main permit increasing the rate of heating, through-heating, and cooling. Annealing without covering allows reducing the heating-up time and shortening the period of cooling in the intermediate stage of annealing. Annealing without covering is carried out in batch-type or continuous furnaces having a protective atmosphere, for example, a neutral or slightly reducing gas produced by a special generator. Of particular importance here is sealing of the furnace to prevent the gas from escaping into the room and poisoning the operating personnel.

Inoculating liquid iron. Inoculation increases the number of centers of graphitization. Aluminum, bismuth, and boron are most popular inoculants. The mass percentages of inoculants added to the iron are the following: 0.015-0.03% Al, 0.002-0.004% Bi, and 0.002-0.004% B. The process of annealing that combines slow heating from 250 to 450°C with holding at this temperature range for 3 or 4 h produces the best results.

In inoculating white iron, magnesium encourages chilling, permits performing the annealing treatment at a higher temperature and obtaining globular graphite.

Alloying malleable iron. Graphitizing elements such as silicon, nickel, and copper can serve here as alloy additives. Silicon and aluminum promote the growth of graphitizing centers and speed up the process of graphitization. The amount of silicon added to the iron should not be excessively high, otherwise it would promote the formation of primary graphite in castings. Nickel and copper accelerate the diffusion of carbon and speed up somewhat the process of annealing, but nickel is an expensive and critical material, for which reason its use is undesirable. Copper added to iron in an amount of up to 1.5-1.7% shortens the annealing cycle by approximately 30% and aids in increasing the strength of malleable iron.

Preliminary hardening of castings. The length of annealing after hardening at 950°C comes to 15-20 h for castings with a small thickness of walls. This is because the number of centers of graphitization sharply rises after hardening. Such a method of annealing can only be used for castings of simple shapes.

Part V

PRODUCTION OF STEEL CASTINGS

Chapter 1. STEELS FOR SHAPED CASTINGS

1.1. GENERAL

Steel castings find wide uses in various branches of industry. Castings made from steel range in mass from several grams to a few tens of tons; the configuration of these castings may be very complex. Steel possesses high strength and ductility, stands up to substantial stresses under variable and impact loads. Alloy and special steels feature good mechanical properties at increased temperatures, show high acid resistance, scale resistance, wear resistance, and other important service properties. Castings from alloy and special steels find increasing uses in new fields of industry.

Classification of steels for shaped castings. These steels are classified by the chemical composition, structure, method of production, and by the application.

By the chemical composition, steels are divided into carbon and alloy-treated types. By the carbon content, steels are classified as low-carbon (0.09-0.2% C), medium-carbon (0.2-0.45% C), and high-carbon steels (over 0.5% C). By the content of alloying elements, steels are divided into low-alloy (about 2.5%), medium-alloy (2-10%), and high-alloy types (over 10%).

By the structure, steels are classified as hypoeutectoid types which have free (hypoeutectoid) ferrite, the structure being typical of carbon and low-alloy steels; hypereutectoid types with secondary carbides liberated from austenite, the structure being characteristic of high-carbon (0.83-1.7% C), medium-alloy and high-alloy steels; ferritic and semiferritic types high in chromium, tungsten, molybdenum, vanadium, silicon and other elements that narrow the austenite region on the constitutional diagram; and austenitic and semi-austenitic types high in nickel, cobalt, and molybdenum.

Steel castings are commonly subjected to heat treatment, therefore steels are also classified according to the structure that results from heat treatment after holding in the air. The heat-treated steels are classified into *pearlitic* types where austenite decomposes in the region of its lowest stability to yield a pearlite-ferrite mixture, the structure being specific to carbon steels, low-alloy, and medium-alloy steels; *martensitic* types where overcooling of austenite during heat

treatment causes it to decompose to yield martensite; *austenitic* types, in which the temperature of the beginning of martensitic transformation is below zero, the structure being typical of Hadfield steel, high-alloy heat-resistant and high-temperature steels.

This classification is arbitrary, since a change in the rate of cooling of steels belonging to the pearlitic class can produce a martensite structure.

By the method of production, steels for shaped castings are divided into open-hearth (basic and acid), Bessemer, and electric furnace steels (basic and acid).

Basic open-hearth steel is most often used for large castings because it has good properties, low cost, and can be melted in large quantities. Electric furnace steel (both basic and acid types) is commonly melted in arc furnaces, and high-alloy steel in induction furnaces.

By the application, steels are classified into structural steels for the production of cast machinery parts, the structural steels being further subdivided into carbon and alloy-treated types and often grouped according to the purpose they have to serve (for hydraulic turbines, electric machines, railway transport, and so on); into tool steels, which commonly include high-alloy and high-carbon types; and into special steels such as corrosion-resistant, wear-resistant, scale-resistant, acid-resistant, high-temperature, and other types, which usually fall into the high-alloy class.

1.2. CARBON STEELS

Carbon steels find most extensive use for shaped castings. The composition includes carbon, manganese, silicon, phosphorus, and sulfur. It is carbon that exerts the main influence on the mechanical and casting properties of steels. Sulfur and phosphorus are harmful admixtures of steel. Sulfur reduces the fluidity of steel at high temperatures and makes it more susceptible to hot cracking. Phosphorus decreases the impact strength of steel, and does so more intensely as its content grows. The contents of phosphorus and sulfur in steel are specified within certain limits. The permissible total content of sulfur and phosphorus must be lower than 0.1%.

With an increase in the carbon content of steel, the ultimate strength, hardness, and yield strength grow, while the elongation, necking (reduction in area), and impact strength decrease. Manganese has a deoxidizing action and neutralizes the adverse effect of sulfur, forming in the reaction with sulfur the chemical composition MnS. The contents of manganese and sulfur in carbon steel must conform to the relation $Mn \geq 1.71 S$. The content of manganese usually varies from 0.3 to 0.8%. Silicon present in carbon steel acts as a deoxidizer and fixes gases. Carbon steels contain 0.2-0.5% Si.

Depending on the purpose and the requirements they have to fulfil, steel castings are divided into three groups: group I includes

general-purpose castings; group II, high-purpose castings; and group III, special-purpose castings which have to comply with the most stringent requirements.

These groups differ by the contents of sulfur and phosphorus. For castings of group I, the allowable contents of these elements are 0.05-0.07% S, and 0.05-0.08% P; for group II castings, 0.045-0.06% S and 0.04-0.07% P; for group III castings, 0.045-0.05% S and 0.04-0.05% P. The content of other elements is the same in castings of all the three groups. Castings show the same mechanical properties, irrespective of the group they belong to.

Low-carbon steels contain 0.12-0.2 % C, 0.35-0.65% Mn, 0.15-0.25% Si, about 0.06% P, and near 0.05% S. Low-carbon steels have a lowered fluidity and enhanced tendency to form hot cracks in castings. The tensile strength of these steels after cooling in the annealing furnace or normalizing is 394-410 MPa (40-42 kgf mm⁻²), the elongation being 24-23%. Low-carbon steel castings are used in electrical engineering and machine-building industry.

Medium-carbon steels contain 0.22-0.45 % C, 0.35-0.8 % Mn, 0.2-0.45% Si, 0.03-0.05% P, and 0.03-0.05% S.

These steels have better casting properties than low-carbon steels, that is, they are more fluid and less susceptible to hot cracking. The tensile strength is 410-540 MPa (42-55 kgf mm⁻²), and the elongation 23-12%. These steels are used for casting small, medium-sized, and large parts employed in various branches of the machine industry.

High-carbon steels contain 0.45-0.6 % C, 0.5-0.8 % Mn, 0.04-0.05% P, and 0.04-0.05% S. These steels show a high fluidity and are not subject to hot cracking. But since the thermal conductivity of these steels is low, castings are more exposed to the danger of developing internal stresses. High-carbon steels are used for casting hot rolls, gears and drums of mobile hoist machines.

1.3. ALLOY CAST STEELS

Alloy cast steels find use in the production of castings which must have improved mechanical properties, enhanced resistance to wear, corrosion, heat, and so forth. The alloying elements commonly used here are Cr, Ni, Mo, V or Si, and Mn.

Manganese cast steels come in three types, low-alloy (up to 2 % Mn), medium-alloy (2.5-4% Mn), and high-alloy (up to 20% Mn). Low-alloy steel shows improved mechanical properties, as against common carbon steel, and compares with the latter in casting properties. Medium-alloy steel has enhanced wear resistance and high strength, but low plastic properties. This steel is suitable for gears, cams, and other parts operating under friction conditions.

High-alloy steel (up to 13% Mn) enjoys most extensive applica-

tions. It is well stable to wear under impact loads. The uses include track shoes of crawler-mounted machines, excavator bucket teeth, and others. An increased manganese content imparts fluidity to steel, but raises its shrinkage and tendency to form hot cracks and oxide spots in castings.

Chromium cast steels come in low-alloy (1 or 2% Cr), medium-alloy (3 to 5% Cr), and high-alloy grades (30% Cr).

Low-alloy steel works well in abrasion, has high strength, but insufficient ductility. Small percentages of molybdenum, vanadium, and tungsten added to low-chromium steel raise its ultimate strength to 1 862 MPa (190 kgf mm⁻²). Medium-alloy steels have increased strength at high temperatures and resist well the attack by some chemical substances. High-alloy steels feature enhanced high-temperature strength at temperatures approaching 1 100°C.

Chromium cast steels exhibit low fluidity. High-chromium steels have high shrinkage and tendency to develop cracks and shrinkage cavities. Overheating before pouring and an increased pouring rate (double the pouring rate for carbon steel), make chromium steel fill better the molds.

Chromium-nickel cast steels have high strength, increased ductility, corrosion resistance, and high-temperature strength. Low-alloy steels of this type contain 1 or 2% Cr, 1.5 to 3% Ni, 0.2 to 0.5% C. They show enhanced strength.

Chromium-nickel corrosion-resistant steels are highly heat resistant. They contain 0.1-0.4% C, 0.8-1% S, 0.4-0.6% Mn, 17-19% Cr, and 7-9% Ni.

Examples of uses are parts of steam and gas turbines and other parts designed for high-temperature service.

Chromium-nickel cast steels are inferior to common carbon steels in fluidity. In order that they fill better the molds, these steels need overheating and high speeds of pouring. Solidification of castings gives rise to a coarse-grained macrostructure which fosters hot cracking. For this reason, in running the castings from chromium-nickel steels, it is advisable to resort to multiple gating to avoid local overheating, use well deformable cores and molds, and choose the correct pouring temperature for every casting.

Silicon cast steels exhibit an increased wear resistance and chemical stability. Low-alloy steels of this type contain up to 2% Si, and high-alloy steels up to 20% Si. High-alloy steels are very hard and brittle, and low-alloy steels are highly susceptible to hot cracking, which necessitates molds and cores of good deformability and slow and uniform cooling of castings.

Industry also employs copper cast steels for the production of cast crankshafts, pistons, and other parts, and tungsten cast steels for cutting tools. Tungsten cast steels have low fluidity and increased shrinkage.

Chapter 2. DESIGN OF STEEL CASTINGS AND MOLDING PRACTICE

2.1. DESIGN OF STEEL CASTINGS AND MOLDS

Steels greatly differ in casting properties from gray iron. They have a larger linear shrinkage (2 to 2.5%), lower fluidity, and higher susceptibility to segregation. For obtaining sound castings, one should consider the specific features of steel casting properties at the design stage of a part or at the stage of its manufacturability evaluation.

The design of the individual elements of a steel casting and the combination of these elements should ensure progressive solidification and adequate feeding of the casting. The casting should smoothly vary in thickness; large accumulation of metal at the junction of walls is inadmissible. It is desirable that the casting walls be as uniform in thickness as possible.

In designing the gates and choosing the position of a casting in the mold, it is necessary to provide for such an entry of metal into the mold cavity as to enable progressive solidification of the casting.

Whether or not the chosen arrangement of individual parts of the casting ensures the correct solidification can be verified by applying the rule of inscribed circles. According to this rule, the diameters of the circles inscribed in the casting section must progressively increase from a lower to an upper part of the casting since every upper part acts as a riser for the adjacent lower part. For example, the position of the casting in the mold as shown in Fig. 188a will effect directional solidification and good feeding of the casting. The arrangement shown in Fig. 188b will cause shrinkage porosity in the lower section of the casting.

The rule of inscribed circles also permits evaluating the technological effectiveness of the casting design. As seen from Fig. 188c, the smaller the diameter of the circle inscribed in the area formed at the junction of walls, the smaller the probability that shrinkage porosity will appear in this joint.

It is usual practice to place risers on the top of massive members of a casting for feeding metal, and also to set up external and internal chills for equalizing the rate of cooling in the massive and thin sections of the casting.

While choosing the pouring position for a casting in the mold, one should keep in mind that large flat surfaces have a tendency to develop rat tails. Such surfaces should lie in the lower part of the mold and occupy a vertical or inclined position. The same also concerns thin walls of the casting.

A high shrinkage of steel and the effect of shrinkage retardation by the mold and cores may cause substantial stresses and cracks in the casting. This is particularly the case for intricately shaped castings. To eliminate this defect, the position of the casting in a molding box with crossbars should be so chosen that the crossbars cannot

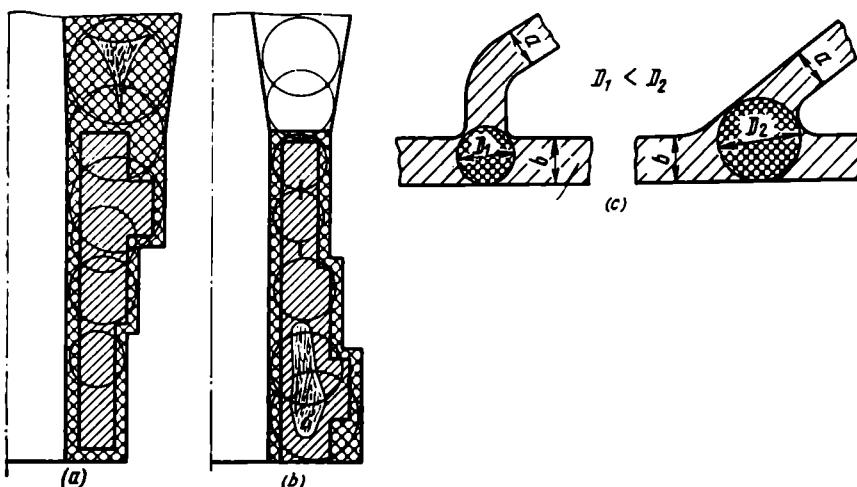


Fig. 188. Determining the technological effectiveness of the design of a casting by the method of inscribed circles

retard contraction of the casting. To effect progressive solidification of a casting, steel should flow directly into the riser or enter it from the bottom and into the thick section. In this case the riser that feeds the casting will be the hottest pocket of molten metal. This induces directional solidification, so that the shrinkage cavity forms in the riser when it ultimately solidifies rather than in the casting.

In determining the position the steel casting must occupy in the mold during pouring and solidification, the designer should be guided by the general principles of casting mold design discussed earlier in the book. The machining allowances for steel castings should be specified in accordance with the data given in Table 30. Steel castings should have larger machining allowances than iron and nonferrous castings because steel shrinks heavily and penetrates deeply into the sand.

In comparison with molds for iron castings, molds for steel castings must be compacted more strongly to prevent erosion of mold walls by the stream of metal. Pouring cups and gates are washed off most heavily. Sand particles carried along with the stream of metal may contaminate the casting. Open risers placed on the cast-

ing members can act as collectors of contaminants. Inclined pouring of large castings is another means used sometimes to eliminate sand inclusions. It is also advisable to increase the machining allowance for the upper part of the casting.

To eliminate the formation of cracks resulting from nonuniform shrinkage, molds should be made from sands of good deformability (see Table 10). Casting ribs (subsequently removed in machining) are a reliable means against the formation of hot cracks. The thickness of these ribs reaches 10-30% of the thickness of casting walls.

External and internal chills sited at the hot spots in the casting induce directional solidification and help overcome the effect of shrinkage.

Chills speed up the process of cooling of thick sections, reduce internal stresses, exclude shrinkage cavities and the formation of hot cracks. Chills are metal objects in the form of rods, wire, and nails either cast or made from rolled stock. The surface of an internal chill must be clean and free of rust or scale. Internal chills must weld up well with the metal of a casting since they will become part of it.

External chills are coated with red lead or molding sand to keep them from welding up to the casting. Before being placed in the mold (Fig. 189), chills 1 should be thoroughly cleaned of dirt, oil, and scale. Internal chills which do not weld up with the metal of a casting are drilled out during machining.

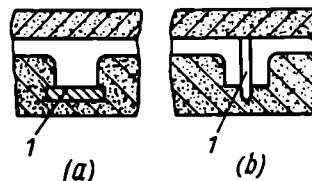


Fig. 189. Placing chills into a mold
(a) external chills; (b) internal chills

2.2. CONSTRUCTION AND CALCULATION OF GATING SYSTEMS AND RISERS

Steels show low fluidity, large volume shrinkage, and have a tendency to absorb gases and form hot cracks. In this connection, the gating systems for steel castings (Fig. 190) must suit the following requirements:

- (1) the length of gates should be as small as possible to enable better filling of the mold;
- (2) metal should enter the mold cavity at the places where the casting members have to solidify last in order to effect directional solidification;
- (3) during pouring the mold, the gates should be completely filled with metal to exclude injection of air and gases from the mold, which can dissolve in the metal or foster cavities in the casting;
- (4) gates should not retard contraction of the casting as it solidifies.

Small and medium-size shallow castings are run at the parting joint or from the top, and massive castings from the bottom. A composite type of gating is suitable for large castings; the first portions of metal enter the mold cavity from the bottom, and the subsequent portions flow into the upper parts of the mold cavity through adequate

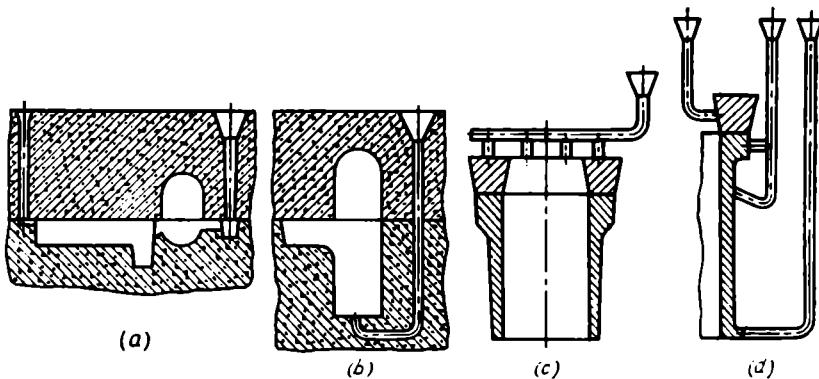


Fig. 190. Designs of gating systems for steel castings
(a) gating at parting joint; (b) bottom gating; (c) top gating; (d) composite gating

tely arranged gates. The basic difference between a gating system for pouring steel and that for iron is that the former calls for setting up large risers to supply feed metal which serves to compensate for shrinkage in the casting. The mass of a gating system with risers accounts for 25 to 50% of the casting. Obviously, it is desirable to raise the casting yield by decreasing the amount of metal required for gates and risers.

Risers are usually placed on the most massive members of castings. Provision should be made for easy removal of risers from the castings. Open risers placed on heavy members of the casting serve as collectors of nonmetallic inclusions floating up to the surface, apart from performing their basic function—feeding the casting to make up for shrinkage. The limitations to the usefulness of open risers (Fig. 191a) are as follows: they should have the height commensurate with the height of molding boxes available at the shop; open risers are holes through which foreign matter may get into the mold cavity; and the amount of metal needed for these risers is excessively high.

Blind risers are set up in high molding boxes, where the use of open risers would entail a large consumption of molten metal. The blind riser shown in Fig. 191b is at atmospheric pressure head with a puncture sand core which heats up rapidly to the metal temperature, and the metal does not solidify round the core. This core connects

the riser with sand layers from which the air passes into the riser interior. The riser thus operates under the atmospheric pressure.

Side risers (Fig. 191c) are used where it is impossible to place risers otherwise, for example, on the top, without running into the danger of casting shape distortion. Blind risers are often made rounded at the top to effect metal savings.

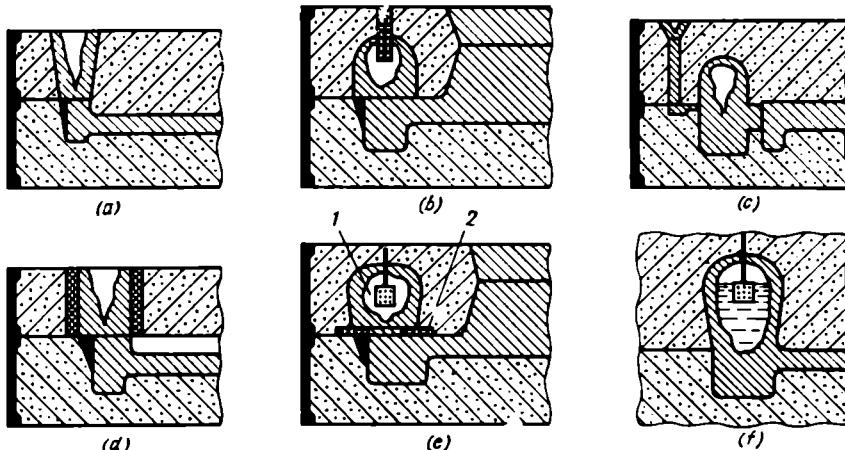


Fig. 191. Ways of placing risers on steel castings

It is very important that the metal in a riser should be kept liquid for very long, otherwise it will not feed the casting properly. Exothermic sleeves (Fig. 191d) made of an antipiping compound, which mainly consists of thermite, are one of the means for holding metal in the riser in the liquid state. The metal poured into the mold causes the sleeve encasing the riser to decompose, yielding a large quantity of heat which heats up the riser. The use of these sleeves for large castings is inadvisable since sleeves burn out well before the riser stops feeding the casting. In this case the effect of the sleeves will be insignificant.

The use of pressure heads operating under excess pressure produced with the aid of a special cartridge 1 (Fig. 191e) permits decreasing the amount of metal required for the riser. The cartridge consists of a shell and a gas producing charge, chalk, for example. After casting the mold, the shell melts down by the moment when a sufficiently strong skin of solid metal builds up on the mold walls (Fig. 191f). Chalk decomposes under heat, evolving gases, which produce excess pressure in the riser interior. The excess pressure provides for better filling of shrinkage pores with liquid metal.

The riser shown in Fig. 191e has a ceramic wafer core 2 to facilitate separation of the riser from the casting. The core heats up quickly

and does not cool the narrowing through which metal flows freely from the riser to the casting. The neck so formed in the riser (called Washburn, or necked-down, riser) permits separating it easily from the casting.

Calculation of gating systems. The total cross section of gates may be found by formula (9). The time (in seconds) the metal takes to fill the mold can be calculated by the formula

$$\tau = s \sqrt[3]{\delta G} \quad (24)$$

where s is a time coefficient, δ is a mean wall thickness, mm, and G is the mass of the casting with gates and risers, kg.

The coefficient s depends on the operating conditions and ranges from 1.4 to 1.6.

For castings liable to develop internal stresses, cracks, and shrinkage cavities, it is desirable to increase the coefficient s by 0.1 or 0.2. Castings produced in metal or sand molds with a large number of chills need a shorter period of pouring. In calculating the pouring time for these castings, the value of s should be decreased by 0.1 or 0.2.

The found pouring time may be verified using the formula

$$v = \frac{H}{\tau}$$

where v is the speed with which the metal rises in the mold, cm/s, and H is the casting height, cm.

If the casting has walls 7 to 10 mm thick, the pouring speed v must be not less than 20 mm/s. With $\delta = 10$ to 40 mm, $v \geq 10$ mm/s, and with $\delta = 40$ mm and over, $v = 8$ mm/s. If the speed v proves insufficient, it is necessary to decrease the pouring time or change the position of the casting in the mold.

According to Professor G. M. Dubitsky, the relations between the cross sections of the gates, runners, and sprues should be as follows: For small castings

$$F_g/F_r/F_s = 1.0/(1.05 \text{ to } 1.2)/(1.1 \text{ to } 1.2)$$

For medium-size castings

$$F_g/F_r/F_s = (1 \text{ to } 1.5)/1.0/(1.05 \text{ to } 1.2)$$

For large castings

$$F_g/F_r/F_s = (1.0 \text{ to } 2.0)/(1.0 \text{ to } 2.0)/1.0$$

Chapter 3. MELTING AND CASTING OF STEELS

3.1. MELTING IN OPEN-HEARTH FURNACES

Foundries use open-hearth, arc, and induction furnaces for melting steel.

Open-hearth furnaces produce steel mainly for large castings. The open-hearth method of melting has the following advantages: permits using a large quantity of steel scrap and refining the initial materials of various chemical composition into liquid steel; produces high-quality steel in a variety of grades; and makes refining durable and cheap in cost. The output capacities of open-hearth furnaces used in foundries of machine works range from 5 to 100 t.

The working space of an open-hearth furnace resembles a large refractory shallow bowl, above which fuel burns to produce a flame with a temperature of 1 800–1 900°C. The heat of fuel combustion melts the charge and overheats the metal. As the solid charge gradually melts down, it forms a liquid metal bath covered with a layer of slag.

The front wall of a furnace has charging doors for introduction of charge materials and fluxes into the furnace. The casting pit has a taphole for discharging liquid steel.

Open-hearth furnaces are of the two types, acid and basic.

The furnace campaign (life) for small- and medium-capacity furnaces with a silica roof varies from 400 to 500 melts, and for large-capacity furnaces 250 to 300 melts. Small- and medium-capacity furnaces with a magnesite roof can stand 700 heats.

Modern open-hearth furnaces are equipped with necessary instrumentation and devices for automatic control of fuel, air and pressure in the working space; automatic devices actuate changeover valves, special mechanisms lift up the gates of charging doors, and so on.

Fuels. At works where the blast-furnace practice is absent, open-hearth furnaces operate on producer or coke gas, or liquid fuel. Works engaged in blast-furnace practice have furnaces run on a mixture of coke and blast-furnace gases with the additions of producer gas or tar to make the flame more luminous.

Melting process. The process can produce either basic or acid open-hearth steel depending on whether the furnace hearth is basic (magnesite) or acid (silica). At present almost all steel is produced by the basic process. This is because the basic process is capable of melting the charge whose content of phosphorus and sulfur is higher than it is in the finished steel. The open-hearth process is adaptable to

the manufacture of carbon, low-carbon, and medium-carbon steels for shaped castings.

The acid open-hearth process embodies certain characteristic features beneficial for the production of fine-grain steel, so that it proves indispensable where the need arises to obtain special high-quality steels.

The scrap-and-pig process that produces steel for shaped castings enjoys the highest popularity.

Basic scrap-and-pig process. In this process, the furnace gas is the basic source of oxygen for the oxidation of iron admixtures. Iron ore charged into the furnace during the heat in an amount of about 30% gives but an insignificant quantity of oxygen. The charge proportioned for melting should contain about 1% Mn, near 0.3% P, near 0.05-0.06% S, and a small percentage of silicon. The charge generally contains about 30% conversion open-hearth pig iron and up to 15% steel shearings, for melting carbon steels, or about 10%, for melting alloy steels. The remaining portion of the metal charge includes purchased scrap and foundry returns. The charge should contain 0.3-0.5% more carbon than the finished steel.

The heat, that is the whole of the melting cycle, commonly comprises the following stages or operations: furnace fettling, charging, melting, boiling, deoxidation, and tapping.

Fettling. The hearth, walls, and banks of a furnace wear out with time and need periodic fettling to keep them in the proper condition. The fettling materials include burnt, ground and screened dolomite or metallurgical magnesite, and, sometimes, crushed raw dolomite. The operation must take a minimum of time to prevent the hearth from oxidation; it usually lasts for not more than 10-15 min. The operation is completed after plugging the taphole with powdered magnesite.

Fettling can be performed mechanically and manually. The operation is started as soon as the bath level during tapping of the molten steel begins to decrease.

Charging. A speedy charging shortens the melting cycle. In this procedure, small-sized scrap (10 to 20% of the total steel scrap) should be laid on the hearth and then limestone (6 or 7% of the metal charge) be dumped onto the scrap. Lime is sometimes substituted for limestone because lime speeds up the melting period and decreases the amount of iron required for the heat. Next bauxite is added and then limestone is heated up for 10-15 min. The heating of limestone being over, conversion pig iron (10-15% of the metal charge) is introduced and then steel shearings are added, on which bulky scrap is laid. After good heating-through of the metal charge, the rest of iron is dumped into the furnace. In the scrap-and-pig process, baffles should be fettled fast to keep them from being coated with molten iron added at the end of the charging period.

Melting. The melting period approximately begins at the end of charging and terminates at the meltdown. This is the longest of all the periods of the scrap-and-pig process. As the charge melts, slag builds up; silicon contained in pig iron oxidizes fully, while manganese and phosphorus only partially. To hasten the oxidation of solid materials, the air is enriched with oxygen. In an oil-fired furnace oxygen is supplied to nozzles and ejected together with air into the furnace.

In running carbon heats, the excess of carbon (soon after the meltdown) over the permissible carbon content of the finished steel should not go beyond 0.3%. If the melt is deficient in carbon, the additions of specular or pig iron are made to the furnace to adjust the carbon content to the desired composition.

By the moment of meltdown, more slag forms from metal charge oxides, limestone, bauxite, and the materials of the hearth and lining. The slag speeds up the bath boil and removal of sulfur and phosphorus. For this, 15 to 40 min before the meltdown, more limestone and bauxite are added to bring the slag basicity, CaO/SiO_2 , to 1.5-2.0. This slag consists of 30-35% CaO , 18-25% SiO_2 , and 10-15% FeO . The meltdown being over, the slag is flushed off to lower the phosphorus content of steel and then fresh-burned lime and bauxite are added to form a new slag of normal basicity, with about 40% CaO and 20% SiO_2 .

The furnace is then adjusted for the lime boil under the cover of new slag, which proceeds at the expense of oxygen found in the bath. The operators gradually raise the slag basicity, bringing it up to 2.2-3.5 by the end of boiling. In the lime boil period, the content of manganese in steel grows as a result of its reduction from the slag. The rate of carbon oxidation can be increased by ejecting oxygen into the bath. The lime boil is the most responsible of the periods as it assists in refining the metal from dissolved and nonmetallic inclusions. This period of melting necessitates periodic analyses of the composition of steel and slag.

When the carbon content has dropped to the desired point, *preliminary deoxidation* (blocking) is performed by adding manganese-silicon, silicon spiegel, and ferrosilicon. After 5 to 10 min, *final deoxidation* is started to adjust the steel to the desired chemical composition. In melting of alloy steels, additions of ferroalloys are made at different moments: nickel is added at the start of the heat along with the charge; molybdenum, in the period of dephosphorization and slag formation; chromium, after preliminary deoxidation; and so on. Final deoxidation is carried out by adding the 45-% or 75-% ground ferrosilicon to the stream of metal as it runs from the spout into the ladle. Aluminum is added directly to the ladle in the proportion 0.8 to 1 kg aluminum to 1 t steel.

Oxygen open-hearth process. The use of oxygen in the open-hearth

practice offers a number of advantages: oxygen speeds up the melting cycle and thus raises the output of furnaces, lowers the amount of fuel required per ton of steel, and permits decreasing the quantity of combustion products.

The process of melting is intensified by adding oxygen to the stream of air, directing an oxygen jet at the scrap, and by oxygen-lancing.

The method in which the furnace receives oxygen fed directly to the ports is most popular. In gas-fired furnaces, oxygen is added to the gas stream as it leaves the gas passage and enters the furnace. Oil-fired furnaces consume 15 to 25m³ oxygen per ton steel. For gas-fired furnaces, the consumption of oxygen comes to 35 m³/t. Furnaces use the oxygen-enriched air mainly during charging and melting-down. This raises the furnace output by 10-12%.

A jet of pure oxygen applied to the scrap hastens the process of melting. The scrap should be melted by the oxygen jet only after heating it to 1 400°C.

Pure oxygen introduced directly into the bath accelerates the oxidation of carbon. Direct oxidation enables much better removal of phosphorus and sulfur. Oxygen is injected through water-cooled tubes or special lances installed in the front or back walls, or, sometimes, in the furnace roof. The consumption of oxygen for direct oxidation of carbon in the bath is equal to 2.5-5.0 m³/t.

Acid open-hearth process. As mentioned earlier, this process is used for melting high-quality steels. The oxidation power of slag in the acid process is lower than it is in the basic process and, hence, the concentration of oxygen in the melt is lower too. The charge materials should have the lowest possible content of sulfur and phosphorus, and the fuel should contain a minimum amount of sulfur.

In use are two variants of the acid open-hearth process, passive and active.

With the passive variant, the process is conducted so that silicon is reduced from the slag and the hearth. The quantity of reduced slag is enough to produce killed steel without adding other deoxidizers.

With the active variant, iron ore or scale is added to augment the oxidation power of slag and lower its temperature. This aids in decreasing the amount of silicon being reduced to 0.1-0.12%. Lime added to the charge also decreases the concentration of silicon in the slag.

3.2. MELTING IN BASIC AND ACID ELECTRIC FURNACES

Special features of melting in arc furnaces. The basic features of electric-arc melting are as follows: the possibility of producing a reducing atmosphere in the working space of the furnace; a high temperature that permits obtaining high-active slags which have one-tenth

the ferrous oxide content of the open-hearth slags; a lower concentration of oxygen in the furnace, which offers the possibility of conducting oxidizing processes by supplying only iron ore or oxygen to the furnace; and a low melting loss of elements.

In the arc zone, however, there is probability of the formation of active nitrogen which is able to dissolve in liquid steel. That is why electric furnace steel contains more nitrogen than open-hearth steel.

The reducing atmosphere, the basic slag, and higher overheat are beneficial for promoting steel low in sulfur.

The electric-arc melting process is harnessed to the production of steel used for small and medium-size castings. The capacities of furnaces employed at foundries producing shaped castings vary from 0.5 to 10 t. Furnaces operating at plants of heavy industry can hold up to 30 t of charge materials. The choice of the melting process depends on the grade of steel and the permissible content of sulfur and phosphorus.

Furnaces with a basic lining are used for the production of high-strength alloy or high-strength high-temperature steels for special-purpose castings. Basic furnaces can produce steel low in sulfur and phosphorus. Charge materials employed in the acid-electric practice must be as low in sulfur and phosphorus as possible.

Of all the electric-melting units, the acid arc furnace is the simplest and most convenient in service. The acid-arc process provides for a long life of lining, thereby making savings in relining costs, consumes less electric energy, shortens the melting cycle, and promotes better deoxidation of steel. These are the reasons why steel foundrymen prefer the acid process over the basic process.

Melting in acid arc furnaces. The lining is constructed from silica or chrome-magnesite brick. Some furnaces are made with a water-cooled metal roof.

The preparatory operations performed before working the heat include cleaning the furnace from the remainders of slag and metal of the preceding heat and fettling the hearth, banks, and walls. Hearth fettling requires quartz sand with over 96% SiO_2 and about 1% impurities.

The charging procedure is as follows: first half the small-sized charge is laid on the hearth, next the medium-sized and bulky charge is placed near the electrodes, and then the rest of small-sized charge is dumped on the top. The excess of carbon in the charge above the lower limit of the finished steel carbon content should be equal to 0.2-0.3%. The silicon and manganese contents of the charge should be such that the melt can have 0.03-0.1% Si and 0.12-0.2% Mn.

The main feature of the acid-electric process is that the heat is under the cover of acid slag containing up to 65% silica. Such a slag does not absorb phosphorus and sulfur, for which reason the charge

should contain a minimum of sulfur and phosphorus — 0.01% below the permissible content of these elements in castings.

After melting of a definite amount of the charge (the meltdown being conducted as fast as possible), the return slag from the previous heat is added to the bath. This slag consists of 38-45% SiO₂, 22-28% FeO, 18-26% MnO, and 6-7% CaO.

The oxidation of carbon and other impurities in the boil period diminishes the carbon content by 0.15-0.2% (for 25-30 min as the bath comes on the boil). To prevent the silicon reduction in the period of bath boiling, limestone is added to decrease the concentration of SiO₂ in the slag.

As the slag assumes a white-green, smoky, or white-blue color, the heat becomes ready for deoxidation with ferrosilicon or manganese silicon. Additions of aluminum made directly in the ladle while tapping the heat provide for final deoxidation.

Melting in basic arc furnaces. The lining is made of special electro-metallurgical magnesite burned into magnesite brick which is laid on heat-insulating brick. The basic-electric practice uses two methods of melting, namely, with and without metal oxidation, the latter being largely employed for remelting. The method of oxidizing melting is used for working the charge whose chemical composition is unknown, or the charge contaminated with phosphorus, and also for producing low-carbon steels. In this method, of importance is bath boiling that arises from the oxidation of carbon, silicon, manganese, phosphorus, chromium, and other elements as they enter into the reaction with the oxygen of iron ore being introduced into the furnace.

Melting with oxidation includes the stages of furnace fettling, charging, melting, deposphorization, boiling, acid slag raking, carburization, deoxidation, desulfurization, and refining. The stages of deposphorization, boiling, and slagging constitute an oxidizing period of melting, and the stages of carburization, deoxidation, desulfurization, and refining make up a reducing period of melting.

The oxidizing period of melting calls for the formation of an oxidizing slag, 30 to 40 min before the charge meltdown. For this, iron ore, burnt lime, and fluorspar are added into the furnace and then iron ore and lime are dumped on the top. The additions are allowed to melt and react with metal, following which 60 to 70% of the slag is raked off and a new slag is formed, the operation being repeated three times. As a result, the phosphorus content of steel is reduced to 0.01%. Deposphorization being accomplished, the period of boiling begins, which indicates the decarburization of the steel. Calcined ore is periodically added in controlled quantities to keep the bath at the boil. Next the furnace temperature is raised and the ore additions are simultaneously decreased in quantity to convert the bath to the quiescent boil which proceeds at the expense of oxygen

found in the bath. Before initiating the quiescent boil, it is necessary to flush off the slag. By the end of the oxidizing period, the carbon content of the steel must be 0.02-0.03% below the lower limit of the finished steel carbon content; the phosphorus content of the steel must be near 0.015%.

The reducing period of melting is the most responsible of the operations. In this period, melting may be conducted by various methods, which differ in the nature of the physicochemical processes of interaction between the melt and the slag. In melting cast steel, foundries most commonly use the variant of melting under white slag, the oxidation being carried out with the aid of ferroalloys added at the start of the reduction period. The white slag consists of 60-65% CaO, 14-16% SiO₂, 10-12% MnO, 5-10% CaF₂, 2.5-4% Al₂O₃, and near 1.5% FeO.

The white slag is formed in the following manner. After removal of the oxidizing slag, ferromanganese is added to the steel to bring the manganese content to the required figure, and then a mixture composed of 80% lime and 20% fluorspar is dumped onto the melt. The amount of mixture being added reaches 1.5 to 3% of the metal mass. After the formation of the liquid slag, additions of lime, fluorspar, and coke dust are made to the bath in a ratio of 8 to 2 to 1. As the slag turns white, powdered ferrosilicon is introduced into the mixture that is supplied to the furnace, the amount of coke being respectively reduced. The white slag is kept stable until the end of melting by adding a reducing mixture consisting of lime, ground ferrosilicon, coke, and fluorspar. The bath is held under the white slag for one hour, during which time the carbon content of steel grows by 0.02-0.04%. Since the white slag contains small percentages of oxides of iron and manganese, the oxides of this type present in the metal pass to the slag.

Melting in induction furnaces. The features that underlie the process of melting in coreless induction furnaces are as follows: the possibility of melting in any medium whose composition is amenable to control; absence of an electric arc or any other heat source that can carburize steel or saturate it with gases; continuous mixing of the bath of liquid metal, which renders the melt more uniform in chemical composition and facilitates degassing and floating of nonmetallic inclusions to the surface; and simple control of the metal temperature. Low interaction between the slag and metal, however, limits the possibilities of process control by varying the slag composition.

The above features make the process most advantageous in the production of alloy steels for special-purpose castings.

Induction furnaces can be basic or acid. Basic furnaces find use for melting high-alloy steels with an increased content of manganese, titanium, and aluminum.

In coreless induction furnaces, melting takes place in an oxygen-deficient medium, which slows down the oxidizing reactions in the bath. In making up the charge, therefore, one must proceed from the fact that the melting process will basically come to charge remelting.

Charge materials are placed in the furnace so that the pieces can lie as close to each other as possible. Large pieces are laid near to the side walls of the crucible, and small pieces in the middle. The high-melting components of the charge must occupy a lower part of the crucible. During melting, the charge is periodically pressed back to increase the compaction of the yet unmelted pieces. As soon as the charge is melted, a slag is formed to protect the metal from oxidation and reduce the melting loss. In the acid process, the slag is formed from the mixture of chamotte and glass. In the basic process, the slag is produced from 70% burnt lime, 20% fluorspar, and 10% magnesite powder. Alloying elements such as ferromolybdenum, nickel, and copper are added together with the charge. Other alloy additions are made to the bath in the following sequence: ferrochromium, ferrosilicon, and then ferrotitanium. The steel is deoxidized with ferromanganese and ferrosilicon added to the furnace, and with aluminum (200 grams per ton steel) added directly to the ladle. Basic induction furnaces can also be adopted for melting with the oxidation of carbon and removal of phosphorus and sulfur. This process is commonly employed for the production of special steels.

3.3. POURING, CLEANING, AND HEAT TREATMENT OF CASTINGS

The quality of castings greatly depends on the pouring temperature, and therefore one should teem steel from the ladle into molds at high temperatures, 1 550-1 450°C.

The ladles used for pouring into molds may be of the tea-pot spout, bottom-pour, and other types. Before tapping steel from the furnace, it is necessary to heat the ladle lining to redness, otherwise the steel will freeze fast and cause the formation of skull. This is especially the case with casting of low-carbon steels.

The shakeout procedure and means used for the purpose are generally the same as for gray and malleable castings.

In shaking out steel castings from the molds, one should give due consideration for the chemical composition of metal and the casting shape.

Practice shows that carbon steel castings should be removed from the molds at the following temperatures: 880°C, for general-purpose castings of simple shape, which do not experience shrinkage retardation; 600°C, for castings with hot spots and nonuniformly varying wall thicknesses, the castings being held in soaking pits after strip-

ping; and 200°C, for special-purpose castings with retarded shrinkage, which are subject to warping and cracking.

The fettling operations here differ from those employed for iron castings because it is more difficult to remove gates and risers from steel castings. In use are various cutting techniques for removal of gates and risers. These are chipping with pneumatic hammers, oxy-acetylene flame cutting, and others, which are also suitable for the removal of the burnt-on sand whose layer is usually thicker in steel castings than in iron castings. Steel castings need fettling before and after annealing. Before annealing, castings are cleaned from the sintered layer of molding sand, and after annealing from scale formed during the heat-treatment operation.

Heat treatment of castings. As steel castings cool and solidify, the coarse-grained structure results, which show low strength properties. To refine the structure of steel castings and release shrinkage stresses, it is usual to subject steel castings to annealing. This type of heat treatment imparts a higher tensile strength and greater elongation and toughness to the steel. The annealing temperature must be 30 to 50°C above the point Ac_3 .

Holding at the annealing temperature should ensure a uniform heating of the castings throughout the section. The time of holding varies from about one hour for thin-walled castings to 4-6 h for large thick-walled castings. An increase in the holding period above the optimal may cause the fine structure to change again to the coarse structure. The holding period being completed, the castings are cooled in the furnace.

Apart from the above operation, steel castings are subjected to other types of heat treatment to impart certain strength properties.

Normalizing is one of the types of annealing, whose purpose is to refine the grain size of the primary structure and prepare the casting for the next stages of heat treatment. The normalizing treatment consists in heating the steel to a temperature a little in excess of the point Ac_3 , and then holding and cooling in accordance with common schedules of annealing.

High-temperature tempering increases the impact strength and reduces the hardness of castings. The treatment involves heating to 500-600°C at a rate of 30-40°C per hour, holding for one or two hours and cooling in still air.

Quench-hardening in liquid media (water and oil) is suitable for annealed small and medium-size castings, the purpose being to raise the strength and impact toughness.

Normalizing with tempering improves plastic properties and increases the impact strength of the steel. When working out the heat-treatment procedure for steel castings, consideration should be given for the fact that it is only permissible to load the castings into the furnace if its heating temperature does not exceed 350°C. If the cast-

ings have an intricate shape and are liable to develop internal stresses, one should reduce the holding time in the temperature range from 650 to 700°C by one half as against the time of holding at a maximum temperature practiced in the annealing or normalizing procedure. After holding at the annealing temperature, the castings should be cooled in the furnace to 300-350°C, the cooling rate being 30 to 50°C per hour for small and medium-size castings, and 25 to 30°C per hour for larger castings more complicated in shape.

The temperature of tempering depends on the required mechanical properties. An increase in the tempering temperature after normalizing improves the plastic properties but decreases somewhat the strength. The length of holding in tempering reaches 2 h for castings with walls 25 mm thick; for massive castings, the holding time should be increased by a half-hour for every 25 mm of the thickness. After holding at the tempering temperature, the castings are cooled in still air. If there is a danger of temper brittleness, the castings should be cooled in water. Alloy-steel castings are given the temper in oil, and Hadfield-steel castings in water. The tempered castings are held in the annealing furnace at a certain temperature to relieve stresses.

Part VI

PRODUCTION

OF NONFERROUS CASTINGS

Nonferrous alloys are cast into parts of various shapes, which can weigh from tenths of a gram to tens of tons. For example, the mass of copper-alloy cast propellers can be as high as 30 t and over.

Good casting properties of most commercial nonferrous alloys offer the possibility of producing castings from these alloys by a number of casting processes such as sand casting, permanent-mold casting, die casting, and other processes. The advanced casting techniques enable foundrymen to raise the dimensional accuracy of castings and decrease the surface roughness and machining tolerances.

The machine-building industry makes wide use of alloys based on copper, aluminum, magnesium, and zinc.

Chapter 1. PRODUCTION OF COPPER-ALLOY CASTINGS

1.1. COMPOSITION AND PROPERTIES OF COPPER ALLOYS

Copper-alloy castings find use in all branches of industry. Examples of copper-alloy castings include fittings, bearings, gears, sleeves, screw propellers, and other parts. Copper alloys are much more expensive than iron and steel, but high antifriction and anticorrosion properties of these alloys render them indispensable for use in many applications.

Since copper is a costly and critical material, designers must strive to substitute, where possible, iron, steel and plastic parts for copper-alloy parts.

Pure copper shows low mechanical and casting properties and thus finds limited application for cast parts. In more common use are alloys based on copper. Copper alloys are divided into bronzes and brasses. Bronzes are in turn subdivided into tin bronzes (alloys of copper with tin) and tinless bronzes which are alloys of copper with aluminum, lead, silicon, beryllium, manganese, nickel, and other elements. Brasses are alloys of copper and zinc (binary types) or multicomponent alloys with the additions of aluminum, silicon, manganese, nickel, iron, and lead.

Tin bronzes. Common commercial tin bronzes contain 2-14 % Sn, 4-5 % Zn, 4-20 % Pb, 1-5 % Ni, near 1 % P, and other elements. Tin improves the mechanical and antifriction properties and raises the corrosion stability of alloys. Zinc improves the mechanical properties, facilitates brazing and welding. Lead gives added antifriction qualities. Nickel imparts antifriction and enhances mechanical properties, improves the structure of lead bronzes and aids in lead grain refinement. Phosphorus increases the wear resistance, antifriction and casting properties (fluidity), but decreases the strength properties as soon as its content rises above 0.04 %. Tin bronze melts at 1 000 to 1 050°C. Its pouring temperature lies at 1 100 to 1 150°C. The casting shrinkage of thin bronze is equal to about 1 %. An addition of aluminum to tin bronze heavily reduces the fluidity and strength and increases the porosity of castings.

Bronzes that contain near 5 % Sn are known as low-tin types, and over 5 % Sn as high-tin types. Cast bronzes are made from individual components (mainly high-tin components) and from secondary standard-composition alloys (mainly low-tin bronzes) remelted from scrap and other rejects.

A high cost and scarcity of tin restrict the use of high-tin bronzes (with 10% Sn and 1% P) to special-purpose parts, largely to

bearings, gears, and other parts which must show high corrosion and wear resistance under high pressures and poor oiling conditions.

Bronzes whose composition includes 6% Sn, 6% Zn, and 3% Pb are suitable for fittings and sleeves; bronzes with 3% Sn, 7% Zn, 5% Pb, and 1% Ni are used for fittings intended to operate in water and steam at a pressure of 246 to 492 MPa (25 to 50 kgf cm⁻²); bronzes with 10% Sn and 2% P can operate in sea water at a pressure near 300 kgf cm⁻². Aluminum and silicon are considered most harmful admixtures for tin bronzes. The presence of even a few thousandths of a percent (by mass) of aluminum in tin bronze sharply impairs its mechanical properties and pressure-tightness.

Tinless bronzes. Since tin is a poorly available material, the industry extensively uses tinless bronzes which excel tin bronzes in a number of properties or compare well in others and thus serve as substitutes for tin bronzes. Most of the tinless bronzes are as a rule multicomponent alloys. These bronzes have much better mechanical properties than tin bronzes. Besides, the former feature rather high antifriction properties and corrosion stability.

Aluminum bronzes with 8 to 10% Al are most widespread. Iron that enters the composition of a number of aluminum bronzes (for example, a grade containing 9% Al and 4% Fe) refines the grain size of the structure, raises the strength and improves the antifriction properties. Like iron, nickel raises the strength and wear resistance of bronzes at enhanced temperatures, up to 500°C. Manganese increases the mechanical, anticorrosion, and casting properties of aluminum bronzes.

Lead imparts antifriction properties to aluminum bronzes, which are resistant to attack from sweet and sea water and from many of the aggressive media. Besides, they work well under impact load. The shrinkage of aluminum bronzes is higher than that of tin bronzes. Aluminum bronzes have a tendency to develop cracks as a result of impeded contraction, show an increased gas absorption capacity and high oxidizability under the unfavourable conditions of melting and pouring.

Apart from aluminum bronzes, the machine industry uses silicon, manganese, beryllium, and other tinless bronzes.

Cast brasses. Silicon, manganese, nickel, lead, and aluminum brasses enjoy most extensive applications.

Silicon brass is used for shaped castings as it exhibits high casting properties. Castings from this brass machine well.¹ An addition of 3% Pb made to silicon brass gives it good antifriction properties. A silicon brass containing 3% Si and 3% Pb shows enhanced antifriction properties and surpasses tin bronze in the resistance to sulfuric acid.

Manganese brass finds application in shipbuilding for propellers, propeller blades and other parts operating in sea water under heavy

loads. A brass grade with 2% Mn and 2% Sn is used for worm gear wheels and bushes, and a brass grade with 3% Mn and 3% Fe for parts of sea-going vessels and parts intended for work at temperatures over 300°C.

Multicomponent brasses greatly surpass all other brasses in strength properties. The uses include bearings and accessories.

Lead brass with 1% Pb is employed for the production of parts by die casting, centrifugal casting, and liquid forging processes. This brass machines well and has good mechanical properties.

Casting properties of copper alloys. Tin bronzes are low-fluid alloys since they have a wide crystallization range; the castings are subject to dispersed shrinkage porosity conducive to low pressure-tightness. The shrinkage of tin bronzes depends on the composition and varies within 1.4 to 1.45%. Alloy additives and admixtures strongly influence the casting properties of tin bronzes. Zinc narrows the temperature range of crystallization and thus raises the fluidity and pressure-tightness of castings, and also decreases the gas absorption capacity of the melt. Lead imparts pressure-tightness to the alloy as it precipitates between dendrites in the course of crystallization. Phosphorus increases the fluidity since it forms a low-melting phosphide eutectic. Oxygen forms oxides with alloy components and thus sharply lowers the fluidity, pressure-tightness, and other properties of castings. Aluminum, antimony, bismuth and arsenic have an equally adverse effect on the castings.

Aluminum tinless bronzes have a small crystallization range which fosters high fluidity and also good impermeability of castings because the castings are not subject to dispersed shrinkage porosity and are only liable to piping which is easy to remedy by resorting to risers and chills. The shrinkage of these bronzes reaches 2.5%. The bath of aluminum bronzes usually has a dense coat of aluminum oxides formed on its surface in melting and casting. During pouring the oxide coat can break away and get into the mold cavity, causing a decrease in the pressure-tightness of the casting. Quiet pouring of aluminum bronzes into molds without whirling and splashing can eliminate the defect.

Brasses have relatively good casting properties. The shrinkage of silicon brasses reaches 2.3%.

1.2. GATING AND RISERING

Molds for copper-alloy castings are made from molding materials of the lowest gas evolution capacity, small moisture content, and the highest possible gas permeability.

Simple sleeve-type tin bronze castings can be run by using a shower gate (Fig. 192a, b) or a common top gate (Fig. 192c, d). Massive flanges call for the use of chills 1 (see Fig. 192b) placed in the drag

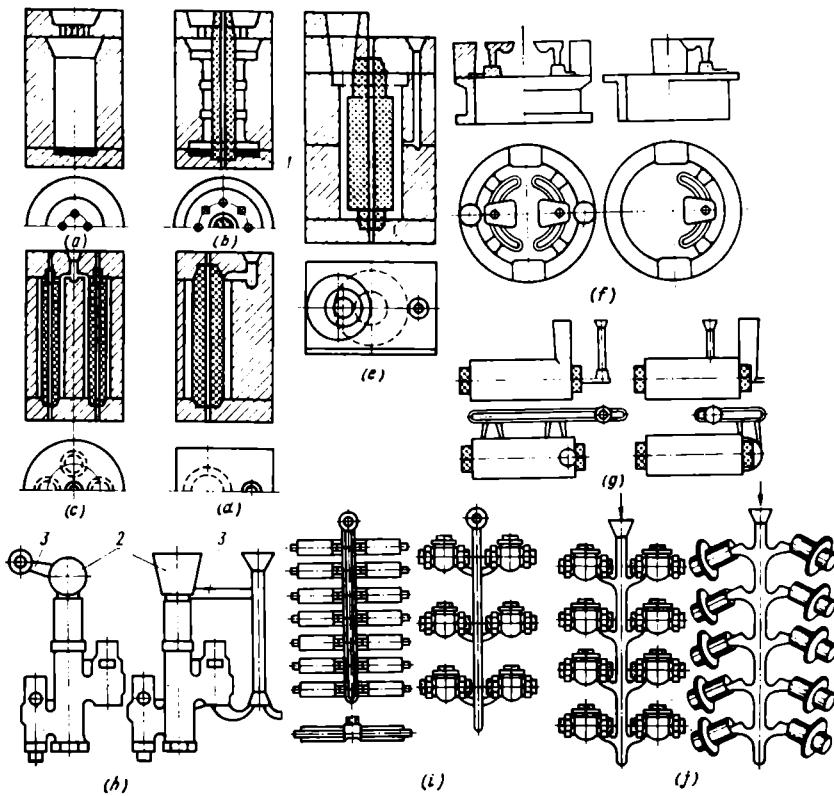


Fig. 192. Gating systems for tin bronze castings

and risers set up in the cope. As seen in Fig. 192e, the metal flows down the sprue, then goes up and fills the riser that feeds the massive flange. Top gating with risers (Fig. 192f) is suitable for running short sleeves. In molding sleeves arranged in the horizontal position, one can use two types of gating as shown in Fig. 192g. If a shaped casting (Fig. 192h) occupies a horizontal or a vertical position in the mold, it is advisable to place a riser 2 on its massive section with an ingate 3 going from the sprue to the bottom of the riser.

To secure quiet pouring in gating such castings as tee-joints at the parting plane and prevent the metal stream from impinging on to the core, the ingates should pass at an angle to the cross gate in a direction opposite to the direction of metal flow, as shown in Fig. 192i. In stack gating of the same castings, the ingates branching from the central gate, or sprue, should be arranged in a similar manner (Fig. 192j). In the gating system used for running castings from sili-

con bronze or manganese brass, the melt enters the mold cavity from the bottom into a lower riser. Filter cores or steel wire gauze placed into the gating system prevent dirt or slag from entering the mold cavity.

Copper alloys readily oxidize in the liquid state. To guard against splashing and oxidation of copper alloys in pouring, the gating system must secure a quiet filling of the mold cavity. Incompletely filled gates expanding downward comply with the demand. Here, the relations between the cross-sectional areas of the sprue, runner, and the gate are as follows: $F_s/F_r/F_g = 1/2/2$, or $1/2/4$, or $1/4/4$.

The cross section of the sprue, which is the narrowest place in the gating system, is calculated with formula (9). The pouring time is determined from formula (24).

1.3. MELTING COPPER ALLOYS

Copper alloys are melted in crucible, reverberatory, arc, and induction furnaces. Crucible and reverberatory furnaces require much fuel and incur heavy melting losses, for which reason it is more preferable to use arc and induction furnaces. An arc furnace burns out 0.4 to 0.7% copper of the charge mass; in remelting shearings, the melting loss comes to 1-1.5%.

The charge consists of certain copper grades, zinc, tin, lead, standard bronze and brass, and also foundry returns, remelted shearings of bronze and brass, and phosphorus-deoxidized copper which serves as a deoxidizer.

It is advisable to make up the charge for melting bronze from about 40% foundry returns and 30% pigs¹ cast from remelted shearings, the balance being individual components and alloy additions. The charge for brass should contain 30 to 40% foundry returns, the rest being requisite metals and alloy additions.

The charge for high-quality castings usually contains a large percentage of individual components. The charge for less critical castings may contain secondary bronze.

Preparing charge materials. All the charge materials delivered to the foundry shop must have a certificate indicating the percentages of basic components and admixtures found in a given material. Purchased and foundry scrap, gates, risers, and casting rejects should be cleaned of molding sands. Gates with steel wire gauze, chills, and sprigs are separated from the stock and remelted separately; the alloy obtained from these materials is refined to remove iron and then used for unimportant castings. Heavily twisted cuttings contaminated with emulsions, moisture, and iron should be crushed, cleaned in a centrifugal machine, dried, and then purified in a magnetic separator.

Calculating the charge. The calculation consists in estimating the mass proportions of various materials to make up the desired charge for melting it in a furnace to produce an alloy of the specified chemical composition.

The charge is usually calculated for every 100 kg of the alloy. After determining the contents of basic components per 100 kg alloy, using the chemical composition as the basis for the calculation, it is necessary to increase the amount of each component to compensate for an irretrievable loss, that is, the melting loss due to burning-out, oxide formation, and interaction between the alloy and lining of the melting furnace.

This loss varies in quantity with the kind of charge (compact or loose), type of melting furnace, melting procedure, and so on.

The melting loss of elements that comprise copper alloys is on the average as follows: 1-1.5% Cu, 2-3% Al; 2-5% Zn, 1-2% Pb; 4-8% Si, 2-3% Mn, 1.5% Sn, 1.2% Ni, and 10-15% Bi.

Example. Let us calculate the charge for melting bronze of the following chemical composition: 6% Sn, 6% Zn, 3% Pb, the balance Cu. Assume that the percentages of elements irretrievably lost in the course of melting are: 1% Cu, 1.5% Sn, 3.5% Zn, and 1.5% Pb.

Use the following charge materials for melting the alloy: foundry returns, electrolytic copper, pig tin, zinc, lead, and secondary bronze containing 6% Sn, 7% Zn, and 3% Pb.

Perform the calculation for 100 kg of the alloy.

The melting loss of basic elements is: copper, $85 \times 0.01 = 0.85$ kg; tin, $6 \times 0.015 = 0.09$ kg; zinc, $6 \times 0.035 = 0.21$ kg; and lead $3 \times 0.015 = 0.04$ kg.

The quantities of components that make up the charge for the production of 100 kg of the alloy are: copper, $85 + 0.85 = 85.85$ kg; tin, $6 + 0.09 = 6.09$ kg; zinc, $6 + 0.21 = 6.21$ kg; and lead, $3 + 0.04 = 3.04$ kg.

Assume that for producing 100 kg alloy of the desired composition we will use 20 kg foundry returns and 10 kg secondary bronze, the balance being individual components. The problem thus reduces to estimating the quantities of individual components, including the melting loss of elements. For this, determine the quantities of basic elements contained in 20 kg of foundry returns: copper, $20 \times 0.85 = 17$ kg; tin, $20 \times 0.06 = 1.2$ kg; zinc, $20 \times 0.06 = 1.2$ kg; and lead, $20 \times 0.03 = 0.6$ kg.

The quantities of basic elements comprising secondary bronze 10 kg in mass are: copper, $10 \times 0.84 = 8.4$ kg; tin, $10 \times 0.06 = 0.6$ kg; zinc, $10 \times 0.07 = 0.7$ kg; and lead, $10 \times 0.03 = 0.3$ kg.

Find the total content of basic components in 20 kg of foundry returns and 10 kg of secondary bronze: copper, $17 + 8.4 = 25.4$ kg; tin, $1.2 + 0.6 = 1.8$ kg; zinc, $1.2 + 0.7 = 1.9$ kg; and lead, $0.6 + 0.3 = 0.9$ kg.

Determine now the quantities of individual components to be added to the charge for the production of the alloy of the specified chemical composition: copper, $85.85 - 25.4 = 60.45$ kg; tin, $6.09 - 1.8 = 4.29$ kg; zinc, $6.21 - 1.9 = 4.31$ kg; and tin, $3.04 - 0.9 = 2.14$ kg.

The composition of the charge for 100 kg bronze of the required chemical composition will be (in kg)

Foundry returns	20
Secondary bronze	10
Electrolytic copper	60,45

Pig tin	4.29
Zinc	4.34
Lead	2.14
Total	101.19

Melting tin bronzes. Before charging, the melting furnace is thoroughly cleaned of the remnants of slag and metal and then the furnace lining is heated to 600-700°C to make it assume a cherry-red color. If the composition of the metal obtained in the preceding heat has contained impurities such as silicon and aluminum, considered harmful to tin bronze, it is necessary to carry out a wash heat.

Copper is charged first into the furnace. If it is impossible to charge all the copper at a time, then it is added in controlled batches in the course of melting. Nickel, if it enters the charge composition, is charged along with copper. In the period of charge meltdown, the yet unmelted solid copper oxidizes to form CuO on its surface. Impurities that enter the charge composition oxidize too in this period of the heat. After melting of the charge, the bath becomes covered with a coat of slag which contains a large quantity of CuO. Charcoal is then dumped onto the molten metal to form a layer capable of protecting the metal from oxidation and burning-out.

Liquid flux proves a more effective means against burning-out and oxidation. The composition of fluxes used for melting tin bronzes in chamotte-lined furnaces is: (1) 41 to 47% SiO₂, 25 to 32% MnO, 11 to 14% Al₂O₃, and 10 to 15% Na₂O, or (2) 50% SiO₂, 30% Na₂B₂O₇, and 20% CaO. The amount of fluxes consumed per heat ranges from 2 to 2.5% of the charge mass.

The fluxes employed for melting bronzes in basic furnaces include (1) borax, Na₂B₂O₇, (2) a mixture of quartz sand with borax in a quantity of 10 to 30%, and (3) a mixture of calcined soda and fluorspar in the proportion 1 to 1. Mixtures with fluorspar are added to graphite crucibles since these mixtures dissolve the chamotte lining.

The molten copper is heated to 1 200°C and then deoxidized by adding 0.3 to 1% of phosphorized copper (depending on the degree of oxidation of the melt). Next the copper is mixed, the slag removed, and then other materials are added in several stages; these are scrap and pigs obtained from remelted chips. Each portion of rejects and pigs is added to the bath after the meltdown of the preceding portion. Before being dumped into the furnace, the charge materials are heated to 100-150°C on the furnace sill.

After heating of the melt to 1 160-1 200°C, zinc is dumped into the furnace. The bath is then mixed, following which tin is added. Lead, if it enters the charge composition, is charged along with tin. The melt is now heated to 1 250-1 280°C, held at this temperature for 5-10 min, and then analyzed for the composition. If the sample has

no oxides and gas bubbles, the heat is tapped into hot ladles. When running thin-walled castings, 0.1 or 0.2% of phosphorized copper is added to the ladle to raise the fluidity of bronze. Molds are poured at 1 150 to 1 170°C.

Melting aluminum bronzes. Along with the above-mentioned components, the charge may contain the following components: metallic manganese; soft iron in the form of sheet shearings and wire or crushed chips free of oil, emulsion, and other impurities; primary aluminum; alloy additions containing iron, manganese, nickel, and aluminum; foundry scrap; and phosphorized copper.

Alloying additions are prepared in the same furnaces as those used for melting copper alloys.

Charge materials are introduced into the furnace after heating it to 700°C and making ready for the run. In melting alloys of various grades (with 9% Al and 4% Fe; 10% Al, 3% Fe, and 1.5% Mn; and 10% Al, 4% Fe, and 4% Ni), it is advisable to lay first copper and iron on the furnace hearth and then place on the top dry birch charcoal to protect the metal against oxidation and burning-out. The bath should be held under the coat of charcoal during the entire run. A substitute for charcoal is the flux composed of 90% crushed glass and 10% fluorspar. The melting period should proceed intensively. After melting the charge and heating the bath to 1 200°C, phosphorized copper is added to deoxidize the melt. Next the alloy additions are made to the melt, first a copper-manganese alloy or metallic manganese, then a copper-aluminum-iron alloy, copper-iron alloy, and later a copper-aluminum alloy. This is the common sequence of introduction of alloy additives into the furnace in the production of any alloy.

Should it be required to add nickel, manganese, and iron to the melt, the sequence of charging is as follows: iron is the first to go, then manganese and later nickel. All the metals should be added before the introduction of alloy additions. Metals and alloy additions are heated before charging. Aluminum is also heated and carefully charged into the furnace in several stages, the melt being mixed after the introduction of every portion. Before tapping the alloy, test pieces are cast to analyze the metal for shrinkage and perform tests in bending. Shrinkage-test specimens are cast in cylindrical dry sand molds, and bending-test specimens in iron or graphite molds. The melt heated in the furnace to 1 200-1 250°C is poured into hot ladles.

Melting silicon brass. The charge materials for melting silicon brass with 3% Si include pigs of standard brass, foundry returns, silicon brass scrap, pigs cast from remelted silicon brass shearings, and silicon. The charge can also be made up of foundry returns and pigs cast from remelted shearings. The furnace being made ready for melting and properly heated, pigs of standard brass are laid on the hearth and melted down. Next the slag is removed and then foundry returns

and pigs cast from remelted shearings of silicon brass with 3% Si are charged into the furnace. After melting down the scrap, the melt is heated to 1 120-1 150°C, thoroughly mixed, slagged off, and then samples are taken to cast specimens for fracture analysis. Additions of silicon are made to the melt, if necessary, in the form of a copper-silicon alloy. The test specimen must show a fine-grained dense structure with a white tint in the fracture and have an angle of fracture of near 30°. The temperature of pouring into molds should be 980-1 080°. For test specimens, the pouring temperature should be as high as 1 000-1 020°C.

Chapter 2. PRODUCTION OF ALUMINUM CASTINGS

2.1. COMPOSITION AND PROPERTIES OF ALUMINUM ALLOYS

Aluminum alloys are widely used in aircraft, automotive-tractor, and other industries. They have high strength, adequate castability, and relatively high corrosion resistance, thermal conductivity, and electric conductivity. Aluminum alloys can be cast into a variety of finished shapes of high strength and pressure-tightness. The cast parts are light in mass and readily machinable.

There are five groups of aluminum casting alloys as regards their chemical composition.

The first group includes alloys of aluminum and magnesium whose content exceeds 4%. To this group belong alloy grades АЛ8, АЛ27, АЛ13, АЛ22, АЛ23, and others. These alloys show low density, high corrosion resistance and are amenable to thermal treatment for increasing the mechanical properties.

The alloys that enter this group are solid solutions which feature increased plasticity after annealing. The parts cast from these alloys can stand up to heavy loads, but show poor performance at elevated temperatures because the solid solutions decompose under heat.

The second group comprises alloys of aluminum with silicon (known as silumins with over 5% Si) and also alloys of aluminum with silicon and small additions of other elements such as magnesium, copper, and manganese. To this group belong such alloy grades as АЛ2, АЛ4, АЛ4В, and АЛ9.

Aluminum-silicon alloys form a eutectic as the silicon content reaches 11.6%. Silumins with 9 to 14% Si, the composition of which is close to a eutectic, are usually modified with the salts of sodium and potassium added directly to the ladle to refine the structure and improve the mechanical properties of the alloys. The alloy АЛ2 is cast into intricate shapes in sand molds, metal molds, and in molding dies. The alloys АЛ4 and АЛ9 contain magnesium. They give enhanced strength to castings and make good materials for large parts intended to work under heavy loads. The examples are crankcases, engine blocks, and other parts.

The third group includes alloys of aluminum with over 4% copper. These are the grades АЛ7, АЛ7В, and АЛ19 which have decreased casting properties and low corrosion resistance. The alloy АЛ7 is used for load-bearing castings of simple shape, and the alloy АЛ19 for critical parts.

The fourth group includes alloys based on the aluminum-silicon-copper systems with 0.2 to 0.8% Mg and 0.2 to 0.9% Mn.

The fifth group includes alloys of a complex chemical composition, which contain silicon, zinc, nickel, magnesium, and manganese. These alloys are noted for high density and good mechanical properties.

The alloys AJ1 and AJ15 are heat-resistant materials. The parts cast from these grades are suitable for high-temperature service. The examples are engine pistons, blocks, and other parts.

Aluminum castings are in many cases heat treated. There are eight kinds of heat treatment applied to aluminum castings, some of which will be mentioned here. Low-temperature tempering, known as artificial aging or precipitation treatment, improves the machinability of castings and raises the strength of parts cast from such grades as AJ3 and AJ5; annealing relieves internal stresses; and hardening increases the strength of parts made from alloys AJ3, AJ4, AJ5, AJ7, and AJ8. In some cases, the strength of heat-treated alloys almost doubles. For example, the strength of the AJ8 grade alloy rises from 128 to 275 MPa (13 to 28 kgf mm⁻²). A list of the compositions of some aluminum alloys appears in Table 57.

Table 57
Composition of Aluminum Casting Alloys

Grade	Basic elements (balance Al)				Admixtures, not over				Total taken into account
	Mg	Si	Mn	Cu	In sand casting	In permanent-mold casting	In die casting		
AJ8	9.5-11.5	—	—	—	0.3	0.3	—	—	1.3
AJ13	4.4-5.5	0.8-1.3	0.1-0.4	—	0.5	0.5	1.5	—	0.7-1.9
AJ2	—	10.0-13.0	—	—	0.8	1.0	1.5	—	2.2-2.8
AJ4	0.17-0.3	8.0-10.5	0.2-0.5	—	0.6	0.9	1.0	—	1.2-2.6
AJ9	0.2-0.4	6.0-8.0	—	—	0.6	1.0	1.5	—	1.2-2.1
AJ7	—	—	—	4.0-5.0	1.0	1.0	—	—	2.2
AJ3B	0.2-0.8	4.0-6.0	0.2-0.8	1.5-3.5	1.0	1.2	1.5	—	1.3-1.8

The mechanical properties of aluminum alloys cast by certain methods and subjected to various heat-treatment procedures are given in Table 58.

Casting properties of aluminum alloys depend on the chemical composition. The alloys of the first group (of the solid solution types) have satisfactory fluidity, increased shrinkage, small resistance to the formation of hot cracks in castings, and low pressure-tightness. The alloys of the second group, which are of the eutectic silumin types, have better casting properties, namely, higher fluidity and lower shrinkage. They do not show a tendency to hot cracking and thus are rather impermeable. The alloys of the third group have relatively low casting properties.

Table 58
Mechanical Properties of Aluminium Casting Alloys

Grade	Casting process*	Heat treatment				Mechanical properties		
		Hardening		Aging**		Tensile strength, Mpa (kgf mm ⁻²)	Elongation, %	BH
		Heating temperature, °C	Holding, h	Temperature of cooling water, °C	Heating temperature, °C			
AJ18	S	435	15-20	20-30	—	275 (28) 147 (15) 147 (15)	9 1 4	60 55 50
AJ13	P, D	—	—	—	—	157 (16)	2	50
AJ12	S, P, D	—	—	—	—			
AJ14	S P	535	2-6	5(10)	175	15	226 (23)	3
AJ19	S P D	535 535 —	12 12 —	5(10)	— 150 —	— 1-3 —	177 (18) 197 (20) 147 (15)	4 2 1
AJ17	S P	515	10-15	5(10)	— 150	— 2-4	197 (20) 218 (22)	6 3

* S stands for sand casting, P for permanent-mold casting, and D for die casting.

** The cooling medium is air.

Aluminum alloys are liable to gas porosity due mainly to the isolation of hydrogen dissolved in liquid metal in the course of crystallization of castings. That is why degassing, or refining, proves to be a very important stage in the melting cycle of aluminum alloys. Porosity leads to the formation of shrinkage cavities. In eutectic alloys, contraction results in piping. In alloys of the solid solution types, contraction causes shrinkage porosity. For these alloys, an increased gas content is particularly harmful since gas fosters porosity and thus lowers the pressure-tightness of castings.

2.2. MOLDS, GATES, AND RISERS

Aluminum castings can be made in green-sand, dry-sand, metal, shell, and other molds.

Sand molds are prepared from fine-grain sands with additions of loam sand instead of clay. Core sands must exhibit high deformability, and binders must burn out at relatively low temperatures.

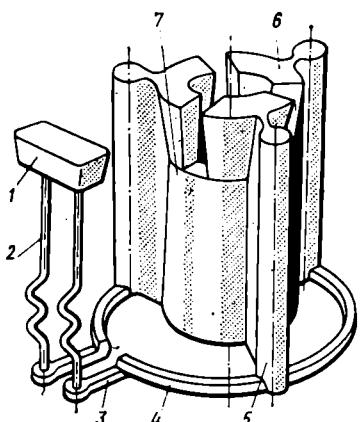
Large castings are run in dry-sand molds of enhanced strength. Medium-size and large molds are made from quick-hardening liquid glass-bonded sands which are subsequently subjected to the gassing process by passing carbon dioxide through the sands, or the molds are heat-dried in the usual manner.

Gating systems. The gating system for an aluminum casting must fill the following demands: ensure quiet filling of the mold without impacts and whirling and thus exclude the entrainment of air and erosion of mold walls; entrap nonmetallic inclusions found in the liquid alloy; promote the escape of air and gases formed as a result

Fig. 193. Top gating system with slit gates and wavy sprues
1—pouring basin; 2—wavy sprue; 3—runner (cross gate); 4—ring gate; 5—slit gate; 6—flowoff; 7—casting

of the decomposition of core sand binders; and effect progressive solidification of the casting. In wide use are bottom gating systems and top gating systems with slit gates which feed the side walls of the casting (Fig. 193).

Bottom pouring enables quiet running of castings but does not provide for the directional solidification from the bottom upwards. The top gating system with slit gates (side risers) is free of this limitation.



In order for the castings to be sound, the pouring speed should not exceed 150 cm/s. Because of this, the gating systems for aluminum casting alloys are made expanding downward, the relations between the cross-sectional areas of the sprue, the runner, and the gate being as follows: $F_s/F_r/F_g = 1/2/3$, $1/2/4$, and $1/3/6$.

To decrease the speed of molten metal, the sprues are often made wavy, though this increases the metal heat loss and does not ensure good filling of the mold. The gating systems are sometimes provided with steel filter gauze to trap the slag.

The cross-sectional area of sprues for aluminum castings may be determined from the nomogram of Fig. 194. The solution of the problem comes to the following. First we lay off the height and mass of the casting on respective scales I, III and connect the points. We then extend the line that connects the above points

until it intersects scale IV and draw a line from the point of intersection to the point indicative of the averaged casting thickness plotted on scale II. Extending this line until it crosses scale V gives us the point that corresponds to the cross section of the sprue for the given casting.

2.3. MELTING ALUMINUM ALLOYS AND POURING MOLDS

Aluminum alloys easily oxidize on melting, dissolve gases and harmful admixtures.

A strong oxide film that forms on the bath surface after melting prevents the metal against further oxidation. The melt may contain such a contaminant as aluminum oxide that does not dissolve in molten aluminum. This oxide can only be removed by the refining process. Aluminum alloys intensely absorb gases, largely hydrogen, which promotes porosity in castings. In melting aluminum alloys, therefore, it is highly important to make the right choice of the charge materials and the melting unit.

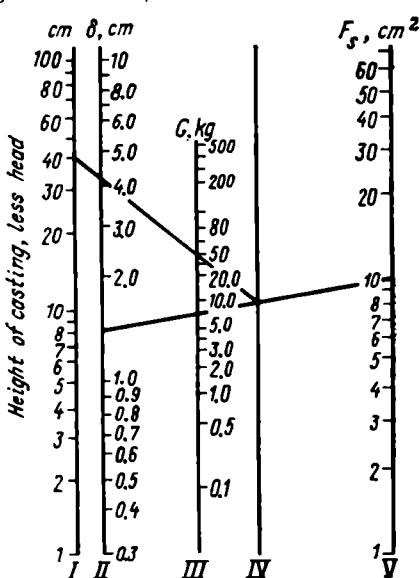


Fig. 194. Nomogram for calculating gating systems used in running aluminum alloy castings

The melting furnaces employed for the purpose vary in construction. The shops producing small batches of castings (up to 30 tons of cast parts for a month) use fuel oil-fired, gas-fired, and electrically-heated crucible furnaces or reverberatory furnaces of small capacity. The shops engaged in the mass production of castings are equipped with gas-fired, oil-fired, and electric reverberatory furnaces, and also with resistance and induction furnaces of large capacity, up to 5 t.

Crucible furnaces mainly serve as distributor (holding) units in shops engaged in the manufacture of die castings and permanent-mold castings. But these furnaces give low output and consume much fuel;

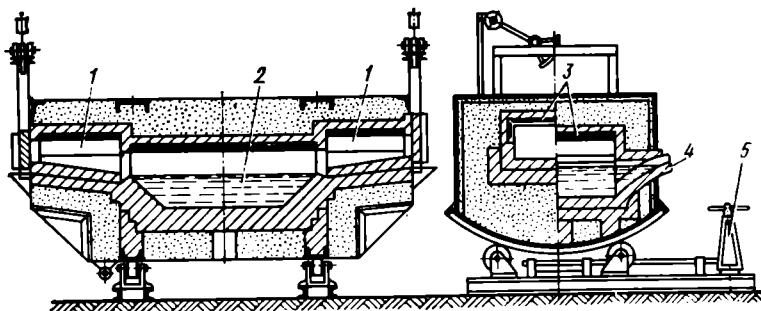


Fig. 195. Resistance furnace for melting aluminum alloys
1—charge chamber; 2—metal receiver; 3—heaters; 4—taphole; 5—drive of the furnace tilting mechanism

the crucibles cast from iron can hold between 125 and 300 kg of alloy. To prevent the iron of crucible walls from dissolving and passing to the aluminum alloy, the crucible is lined on the inside or given a refractory coat which is then burned at 500 to 600°C for 3 to 5 h. The life of iron crucibles ranges from 60 to 100 melts. Apart from iron crucibles, stationary furnaces may have graphite crucibles holding 150 to 300 kg.

Electric furnaces with the heater placed under the bath also find use for melting aluminum alloys.

A furnace of the resistance type (Fig. 195) has two chambers for the charge, in which the metal melts down under the action of heat and flows off into a metal receiver (the basin in the central portion of the furnace), where it is further heated to the desired temperature.

The electric furnaces employed at foundry shops can hold 1 to 3 t and give 5 melts a day, the melting loss being equal to 1%. The electric furnaces of 1.5 to 2 t capacity consume 550 to 600 kW h/t.

Core induction furnaces used for melting aluminum alloys range in capacity from 30-60 kg to 6-8 t. The melting loss averages 0.5-0.8%

and reaches about 5% on remelting shearings. The consumption of electric energy totals 380 to 450 kWh/t.

Calculating the charge. The charge commonly consists of 30-70% scrap (remelted waste, rejected castings, flowoffs, gates, risers, and so on) and 70-30% primary materials such as aluminum and silumin pigs, alloy additions, and metals (magnesium and zinc, and other low-melting and readily oxidizable metals) directly added to the melt. The charge can also contain secondary pig alloys in an amount of 5-10%.

The charge is calculated with due regard for the melting loss of elements constituting the alloy. The melting loss depends on the degree of oxidation of scrap, kind of pig aluminum, performance of the melting unit, method of refining, time of the melting cycles, and on other factors.

The melting loss in electric and crucible furnaces comes to 0.5-1%. In reverberatory combustion furnaces, the loss is higher, 1 or 2%, and even reaches 2.5% if the charge has oxidized heavily.

The melting loss of silicon averages 0.5-1% and depends little on the condition of the charge and the type of melting unit. Magnesium burns out to 2 or 3% and even to 5% on melting a heavily oxidized charge. The copper loss ranges from 0.5 to 1.5%. The products of alloy components lost in melting are present in the bath as oxides. As the metal of a casting undergoes crystallization, the oxides dispose between dendrites and along the grain boundaries and the metal thus becomes low-plastic and brittle. Obviously, the charge should be made up of such materials and so proportioned as to bring the quantity of oxides to a minimum.

Example. Calculate the charge for melting of an aluminum alloy in an electric crucible furnace. The composition of the alloys is: 4.5% Si, 1% Cu, 0.5% Mg, the balance Al.

Assume that the melting loss of silicon, copper, and manganese is 1%, 1%, and 2% respectively. The charge comprises the following materials: silumin with 12% Si, a binary alloy addition with 50% Cu, and alloy addition with 10% Mg. Find the percentages of elements that enter the alloy, taking into consideration the above melting loss of elements:

Silicon

$$\frac{4.5\% \times 1\%}{100} + 4.5\% = 4.545\%$$

Copper

$$\frac{1\% \times 1\%}{100} + 1\% = 1.01\%$$

Magnesium

$$\frac{0.5\% \times 2\%}{100} + 0.5\% = 0.51\%$$

The calculated composition of the alloy thus includes 4.545% Si, 1.01% Cu, and 0.51% Mg.

The melting loss of aluminum need not be specified since it results from the calculated chemical composition.

We will calculate the charge for 100 kg of the alloy.

To produce the alloy of the desired composition, we should take the additions in the following quantities:

Silumin

$$\frac{100 \times 4.545}{12} = 37.8 \text{ kg}$$

Copper alloy

$$\frac{100 \times 1.01}{50} = 2.02 \text{ kg}$$

Magnesium alloy

$$\frac{100 \times 0.51}{10} = 5.1 \text{ kg}$$

So, the mass of additions is

$$37.8 + 2.02 + 5.1 = 44.92 \text{ kg}$$

Consequently, we should add pig aluminum to the charge in the following quantity: $100 - 44.92 = 55.08 \text{ kg}$.

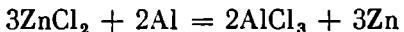
The resultant charge thus consists of 55.08 kg pig aluminum, 37.8 kg silumin, 2.02 kg copper alloy, and 5.1 kg magnesium alloy.

If the charge includes 40 to 60% pig aluminum, the balance being the scrap (gates, risers, casting rejects, and so on), the calculation should be corrected for the melting loss of scrap components.

Melting aluminum alloys. As an example, we shall consider the process of melting of the AJ12 grade alloy. It is advisable to melt this alloy grade from the standard pig alloy or, if it is not available, with the additions of aluminum-silicon alloy. The charge for this alloy may consist of standard pig aluminum, primary aluminum, aluminum-silicon alloy with 12 to 15% Si, 35 to 50% foundry returns, and up to 15% of pigs cast from remelted shearings.

The charge should be dry, free of oil, soil, and other contaminants. The charge materials should be heated to 100-150°C before dumping them into the bath of molten metal. Before charging the materials into the furnace, the thoroughly dried and burned crucible is heated to 600-700°C and then loaded with foundry returns. After melting of the batch, pigs of standard alloy or aluminum (in melting with alloy additions) are added to the bath followed by the aluminum-silicon alloy. The melt is then thoroughly mixed, heated to 680-700°C, and refined by introducing into the crucible hexachlorethane or dry salts of chlorine.

Refining by salts of chlorine. The refining salts that easily decompose under heat include ZnCl_2 , MnCl_2 , C_2Cl_6 , and others. The refining effect of these salts consists in the following. The salt ZnCl_2 , for example, reacts with aluminum

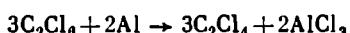


yielding the gaseous aluminum chloride, while the refined zinc passes into the solution. The bubbles of AlCl_3 carry out to the melt surface the particles of oxides and nonmetallic inclusions which go into

the slag. The salts have enhanced hygroscopicity, which is particularly the case for zinc chloride. This salt should be remelted at 380-400°C and ground, and manganese chloride should be dried at this temperature for 4 to 6 h.

The salts must be kept in a constant-temperature oven at 120-150°C. The refining additions are introduced into the bath with a plunger (in an amount of 0.1 or 0.2% salt of the charge mass). The process of refining is considered complete as the bath stops boiling. The salt can be added in two stages to guard against excessive boiling. After refining, the melt is left to stand for 5-8 min to allow the remaining gas bubbles and oxide clusters to float up to the surface.

Hexachlorethane, C_2Cl_6 , used as a refining salt has advantages over chlorides of zinc and manganese. This salt is non-hygroscopic and shows a higher gas evolution capacity as it reacts with molten aluminum; apart from $AlCl_3$, the reaction yields a gaseous product:



The gaseous tetrachlorethane, C_2Cl_4 , floats up in the form of large fast-moving bubbles, so hydrogen has no time to diffuse from the melt into the bubbles. Since this lowers the effect of refining, it is well to add hexachlorethane in an amount of 0.5 to 1% of the charge mass in several portions. The temperature of refining averages 730-750°C.

Refining with fluxes. The fluxes that cover the bath protect molten alloy from the furnace atmosphere and aid in removing oxide inclusions and gas from the melt. The fluxes used for refining include chlorides of sodium and potassium, taken in a ratio of 1 to 1. They form a low-melting eutectic and usually account for 2 or 3% of the charge mass. The flux is added in several portions right after loading the pigs into the furnace. As the first portion of flux melts down, new batches are dumped in succession. The charge meltdown period being over, a flux addition of 0.5 to 1% is made to the furnace to cover the bath, and then sodium fluoride is dropped on the top to thicken the flux. Next the flux is raked off and the heat is poured.

Vacuum degassing. The principle of the vacuum degassing method relies on the fact that as the pressure drops off, the solubility of hydrogen in the melt decreases. Hydrogen, present in the alloy in the ionized or atomic state, passes into the molecular state, forming bubbles, which rise to the surface.

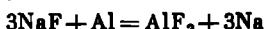
Before pouring it into molds, the alloy is degassed in a special chamber kept under a vacuum of 1 to 10 mm Hg for 10 to 15 min.

The most advanced method of production of high-quality alloy castings relies on melting and pouring in vacuum. Pouring under a vacuum prevents the alloy from oxidation. This offers the opportunity of disrupting the stream of metal that runs into the mold, thereby effecting the progressive crystallization of the casting. Vacuum melting is carried out in vacuum induction furnaces.

Ultrasonic treatment is another method of degassing aluminum alloys. As they pass through the melt, ultrasonic waves induce elastic vibrations of particles. Because of inertia, the separate particles execute a reciprocating motion with different speeds. This causes a temporary discontinuity of the liquid mass and the formation of microvoids found to be at a deep vacuum. The gases dissolved in the alloy fill the voids and form the bubbles. As the particles move in the opposite direction, they compress the gas, but the molecular hydrogen does not go into the solution. The subsequent discontinuities in the liquid promote the growth of bubbles to a critical size, following which the bubbles come to the surface and into the atmosphere.

Modification. This is a necessary technological stage in the production of alloys high in silicon (above 6%) if they crystallize into a binary eutectic α -Si. Coarse, lamellar particles of silicon impair the mechanical properties of alloys and particularly reduce the percentage elongation. Modification is effected with the aid of sodium introduced into the melt in the form of mixtures of salts, NaF, NaCl, and Na_2AlF_6 . The mixture may consist of, say, 67% NaF and 33% NaCl. As the sodium content of an alloy reaches 0.09 to 0.1%, silicon crystallizes into small granular particles, thereby improving the mechanical properties of the alloy.

It is also possible to treat aluminum alloys with modifying fluxes. A flux is first melted, cooled, ground to powder, and screened through a No. 20 sieve. The finished modifier is dumped in an amount of 1.5 to 2% of the charge mass on the surface of the melt heated to the temperature of modification. The melt is allowed to stay under the flux cover for 10-15 min, then the flux is stirred for 2 or 3 min to make it permeate the melt to a depth of 100 to 150 mm. The reaction of the modifier with aluminum proceeds as follows:



After the modification, the flux is made to thicken by adding NaF and then raked off, leaving the alloy ready for pouring. To keep sodium from burning out, the time period from the end of modification to the end of pouring should not exceed 30 min. If this time is not enough to pour the entire melt into the molds, the remaining portion should be modified anew.

Universal modifiers which simultaneously refine the alloys give the best results. The use of high-melting fluxes necessitates substantial overheating of the alloy, which leads to gas saturation of the bath. For this reason these fluxes can be used to good advantage in casting of alloys with an increased content of carbon (in which case the flux should have the highest modification activity) and also in the production of large-size thin-walled parts which must be cast at high temperatures.

In all other cases, it is expedient to use fluxes with a lowered melting temperature.

CHAPTER 3. PRODUCTION OF MAGNESIUM CASTINGS

3.1. COMPOSITION AND PROPERTIES OF MAGNESIUM ALLOYS

Magnesium and its alloys are good structural materials because this metal is 4.5 times lighter than iron and 1.6 times lighter than aluminum. Pure magnesium is a silvery white metal with a melting point of 650°C and density of 1.738 g/cm³ at 20°C. The density of magnesium alloys ranges from 1.75 to 1.90 g/cm³; they surpass some structural steels, irons, and aluminum alloys in specific strength, and show the ability to absorb vibrations, which feature is of much importance for aircraft and other transport industries. Magnesium alloys machine easily and compare to aluminum alloys in corrosion resistance after requisite treatment. These alloys find extensive use in the aircraft industry, instrument engineering, automotive industry, radio engineering, and in other industries. Magnesium alloys can be cast into parts 300 to 500 kg in mass.

In most widespread use in industry are the magnesium alloys of Mg-Al-Mn and Mg-Al-Zn systems. The basic alloying element for magnesium alloys is aluminum, which is added directly to molten magnesium in quantities of 5 to 11%.

Aluminum decreases the tendency of magnesium alloys to self-ignition, improves the mechanical and casting properties. With an increase in the aluminum content, the alloy becomes less strong and more brittle.

Zinc added in an amount of 5.5% imparts strength but worsens the casting properties of magnesium alloys. Zinc-containing alloys are superior to alloys of the Mg-Al-Mn system in corrosion resistance.

Manganese is added to magnesium alloys in quantities of up to 2.5% and to Mg-Al-Zn alloys in amounts of 0.1-0.5% to raise the corrosion resistance. Manganese additions of 1.5 to 2% increase the mechanical properties and pressure-tightness of castings, improve the weldability, but impair the fluidity and render the alloys liable to hot cracking.

Zirconium refines the grain size of alloys, improves the mechanical properties, but decreases the castability.

The magnesium-manganese alloy, grade Мл2, finds comparatively rare uses because of low mechanical and casting properties. Most widespread are magnesium-manganese alloys of grades Мл4 and Мл5.

Alloy Мл4 with 6 % Al, 2.5 % Zn, 0.3 % Mn, the balance being Mg, shows high mechanical properties in the cast state and increased corrosion resistance after oxidation. This alloy is cast into parts of ma-

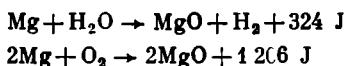
chines and devices which should have high resistance to corrosion. But the alloy heavily oxidizes in the casting process and has a tendency to form microscopic voids, hot cracks, and shrinkage cavities. These factors cause difficulties in casting intricate shapes.

Alloy Мл5 with 8.5% Al, 0.5% Zn, 0.3% Mn, the balance being Mg, has higher casting properties than the alloy considered above since it is less liable to microporosity and hot cracking; it is second only in fluidity to the alloy grade Мл6 (10% Al, 1% Zn, 0.3% Mn, the balance Mg). The grades Мл5 and Мл6 are cast in sand molds, metal molds, and in molding dies for the production of high-bearing parts. Other alloys of this system, grades Мл9, Мл10, Мл12 and others, are cast into parts intended to operate at increased temperatures of the order of 150 to 350°C.

3.2. MOLDS AND GATES

Magnesium alloys are liable to heavy oxidation and even spontaneous inflammation in melting and casting.

When pouring a magnesium alloy into a sand mold which does not contain any special protective additives, magnesium reacts with moisture and oxygen of the air found in the mold pores and also with silica at the hottest spots of the mold. Reactions are attended with the maximum heat evolution and alloy burning. The following reactions are possible:



To prevent magnesium from burning in the mold, the *composition of molding sands must include protective additives*. These are fluorine compositions such as ammonium fluoride or ammonium fluoborate, NH_4BF_4 , or mixtures consisting of boric acid, HBO_3 , urea, $\text{CO}(\text{NH}_2)_2$, and aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$. Additions of 85% NH_4 or NH_4BF_4 and 15% HBO_3 are introduced into molding sands in an amount of 4 to 8% of the sand mass. Core sands are prepared with a mixture of boric acid and sulfur, added in a quantity of 0.25 to 1%. The components of additives react with magnesium or with the products of its oxidation and form protective films of the compositions $\text{MgO}\cdot\text{B}_2\text{O}_3$, $\text{Al}_2\text{O}_3\cdot\text{B}_2\text{O}_3$, and others on the metal surface, which are denser than MgO films. Besides, the additives yield gaseous products which form a neutral gas coat. This gaseous shell keeps the metal against contact with water vapors and gases in the mold.

Gating systems. Pouring basins must be made large to trap the slag. It is advisable to use a top gating system with slit gates. To guard against shrinkage porosity, one can speed up the solidification of metal by arranging external chills at certain places in the mold and implementing the requisite feeding of the casting.

A gating system for casting magnesium alloys may be calculated by formula (9). The relations between the cross-sectional areas of the gating system elements are as follows:

$$F_s/F_r/F_g = 1/2/4, 1/3/4, 1/3/6, 1/4/2$$

Foundries extensively use a sand-mold casting method developed by professor A. G. Spassky and academician A. A. Bochvar. By this method, the mold made ready for pouring is placed in an autoclave, which is then hermetically closed. Next the metal is teemed from the ladle into the mold through a special hole. After pouring, the hole is sealed and then the compressed air is fed into the autoclave to keep it under an excess pressure of 490 to 685 kPa (5 to 7 kgf cm⁻²). The pressure adds to the feeding effect of risers and, at the same time, prevents the evolution of gases from the solidifying metal. This method raises the density of castings and improves their mechanical properties.

3.3. MELTING MAGNESIUM ALLOYS

Magnesium alloys are melted in gas-fired, oil-fired, resistance, and induction furnaces.

Crucible furnaces used for melting magnesium alloys have either lift-out or stationary crucibles. Stationary crucible furnaces can hold up to 900 kg, with an output of about 250 kg/h.

Reverberatory furnaces of large capacities are employed for continuous melting of magnesium alloys and for remelting bulk scrap and rejects. Line-frequency induction furnaces are progressively coming into wider use. The furnaces have a magnesite lining. The finished molten alloy is poured into holding crucible ovens by a centrifugal pump which can transfer the liquid metal for a distance of up to 10 m.

Charge materials and fluxes. The charge may consist of component metals, primary alloys, foundry returns, preliminary alloys and additions. The primary components added to the charge include pig magnesium, pig aluminum, crystalline or pig silicon, pig zinc, and also silumins.

The alloy additions used in melting magnesium alloys are: an aluminum-beryllium alloy (95-97% Al and 3-5% Be, with a melting point at 700-800°C); magnesium-manganese alloy (96-98% Mg and 2-4% Mn, with a melting point at 700-800°C); aluminum-manganese alloy (88-92% Al and 8-12% Mn, with the melting point at 770-830°C); aluminum-magnesium-manganese alloy (70% Al, 20% Mg, and 10% Mn, with a melting point at 700-800°C); and others.

The charge may include the foundry returns of various kinds, which account for 30 to 40% of the charge mass. Magnesite or chalk added to the alloys serves as a modifier.

Metallic calcium is used as an alloying component to raise the density of castings.

The fluxes employed in melting magnesium alloys must satisfy the following requirements: (1) be inert to magnesium or alloy components and to furnace lining; (2) have a lower melting point than magnesium and its alloys; (3) show good fluidity to cover the entire surface of the melt with a dense coat, thus effectively protecting magnesium from contact with the air; (4) have a higher density in the molten state at 750°C than magnesium and its alloys, otherwise the refining flux can get into the melt and contaminate the alloy; and (5) be cheap and readily available.

Table 59
Composition of Fluxes, % by Mass

Type	Basic component					Admixture, not over		
	MgCl ₂	KCl	CaF ₂	BaCl ₂	MgO	CaCl ₂ , NaCl	MgO	Unsoluble residue
1	38-46	32-40	3-5	5-8	—	8	1.5	1.5
2	33-40	26-36	15-20	—	7-10	6	—	1.5

Table 59 shows the composition of two types of most widespread fluxes. The first type is used for melting magnesium alloys in stationary crucibles. It has a dual purpose of the coating flux and refining flux. The second type finds use in lift-up crucibles (melting pots).

Melting magnesium alloys. As an example, we shall consider here the process of melting the alloy Mn5 in stationary crucibles. The production of this alloy requires the use of the first type flux. Before starting the heat, the ladles, bowls (socket cups), and other pouring appliances are washed with cryolitic flux at 750-800°C.

The crucible heated to a dark-red color is charged with the powdered flux in a quantity of 0.1 to 0.25% of the charge mass. The intermediate melt is poured out to have the crucible two-thirds full of the alloy, following which primary alloy pigs heated on the furnace ledge to a temperature not lower than 120°C are added to the bath. After heating the melt to 700-730°C, beryllium is introduced, and then the alloy is modified with magnesite.

Magnesite is crushed to pieces 10 to 25 mm in size, dried at 150-200°C, and added to the bath in a quantity of 0.25-0.3% of the charge mass in a single batch with a closed type plunger, which is submerged into the bath to approximately one-half of the crucible height. The modification period takes 5 to 10 min. The sites of metal burning are coated with ground flux. After the modification, the flux is struck

off from the bath and then powdered flux is sprinkled on to the surface of the melt.

Instead of modification of the alloy with magnesite, it is possible to modify it by overheating, that is, by raising its temperature to 870-900°C (when melting in lift-up crucibles) or to 830-860°C (when producing the alloy in stationary crucibles). The time of holding at these temperatures ranges from 10 to 15 min. After the modification at 700-730°C, the alloy is refined by stirring it intensively for 3-5 min, while pouring the dry ground flux on to the melt surface.

The amount of flux used in the refining stage comes to about 1% of the charge mass. The total quantity of flux consumed during melting and refining reaches 3 to 5% of the charge mass.

After refining and slagging, it is necessary to cast shrinkage test specimens and test pieces for chemical and spectral analysis, coat the bath with fresh flux, heat the melt to the pouring temperature and leave it to stay for 15 min. Before pouring, the ladles are washed with the molten cryolitic flux, heated to redness, and then the remaining flux is run off through the ladle spout. While pouring the metal from the crucible into the ladle, one should coat the metal surface with the flux. The subsequent ladling should start 3 to 5 min after filling the first ladle. It is impermissible to add the flux to the stream of metal poured into the mold. Care should be taken to prevent the slag from being entrained by the metal. The places of metal burning should be covered with a mixture of sulfur and boric acid or with sublimed sulfur.

Basic safety rules in melting magnesium alloys. Magnesium and its alloys ignite in the open air at 400 to 500°C, depending on the composition. They burn with a dazzling white flame, evolving a large quantity of heat and fumes. The alloy M_g5, for example, self-ignites at 400-430°C. The dry dust of magnesium and its alloys spontaneously ignites with explosion at 400-480°C, and the moist dust at 360-380°C. Water or foam fire extinguishers cannot be used to suppress the fire because of the danger of explosion. The reaction of magnesium with water yields hydrogen which mixes with oxygen to form a detonating mixture if the content of H₂ exceeds 9%.

The universal means for quenching the burning of magnesium and its alloys is a dry ground flux applied in melting of magnesium alloys. This flux should always be available at the working places and kept in sealed boxes. Cartridges charged with the flux are good means for putting out the fire when machining magnesium alloys.

The shoproom intended for melting and pouring the magnesium alloys should be isolated from other rooms with fire-resistant walls and metal beams. The melting shop should have an emergency exit, one for every furnace, to allow escape in the event of fire.

Part VII

**SPECIAL CASTING
PROCESSES**

Chapter 1. PERMANENT-MOLD CASTING

1.1. GENERAL

Casting in metal molds (permanent molds) is one of the techniques of manufacture of castings with close tolerances and smooth finishes. In contrast to sand molds which require fracturing after the production of every casting, permanent molds can be poured repeatedly to obtain a few hundreds of castings and even a few tens of thousands of castings.

The cavity of a permanent mold can be made to a high dimensional accuracy and with a low surface roughness, so that the castings have accurate dimensions and good surface finish in the cast state. A high thermal conductivity of the mold material greatly facilitates the solidification and cooling of the casting and in the main has a positive effect on its mechanical properties. The permanent-mold process is 2 to 5 times as effective as the sand casting process (at the same floor area of the shop). Besides, this process secures a higher casting yield because it decreases machining allowances and, in general, effects savings in metal, cuts down the cost of castings and reduces the consumption of molding sands, makes itself available for mechanization and automation, and improves the working conditions.

A high cost of metal molds, however, makes permanent molding economically unfeasible in piece production. Also, the process tends to form hard spots in iron castings, the elimination of which calls for annealing of the cast products.

Economic and technical factors which govern the choice of this process include the durability and design of permanent molds, the degree of mechanization and automation, and also the nature of production (mass batch, or piece production).

Permanent mold casting makes an advantageous process if it justifies expenses involved in the production of castings including the cost of molds, machining costs, and the cost of waste metal.

Casting in permanent molds proves profitable if each mold gives not less than 200 to 400 small castings and 50 to 200 large castings. The entire production process involves the following stages:

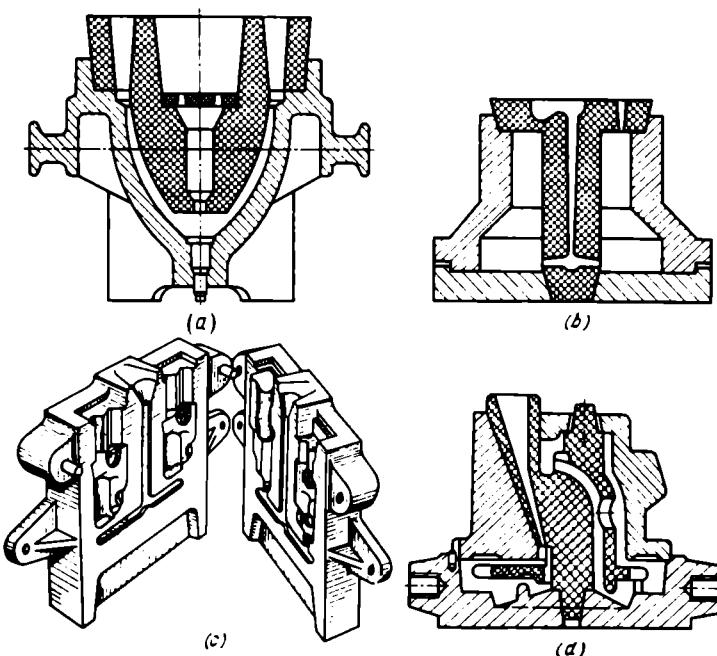


Fig. 196. Permanent molds

(a) unsplit; (b) horizontally split; (c) vertically split; (d) with complex mold joint

1. Preparation of molds, which includes cleaning and heating operations and application of facings and paints to the working surfaces of molds.
2. Assembly of molds, which requires setting the cores in a mold, closing it and fastening the entire mold.
3. Pouring of liquid metal into molds and solidification of castings.
4. Ejection of castings after cooling by opening the molds mechanically or manually.
5. Fettling and, if necessary, heat treatment of castings.

1.2. PERMANENT MOLDS

Permanent molds are generally of cast iron, steel, aluminum, and copper. Small molds are made from cast iron grades СЧ32-52 and medium-size molds from grades СЧ15-32. Large molds are cast from steel.

Gray iron used for the production of molds must have a pearlite-ferrite structure without traces of free cementite since, otherwise, the iron of the mold filled with liquid metal will undergo structural

transformations under heat, which may lead to mold warping. The proportion of ferrite in the iron structure should not exceed 5-10%. An approximate composition of this iron is: 3.4-3.6% C, 1.8-2.2% Si, 0.9-1% Mn, 0.12-0.15% P, and up to 0.3% S. The critical parts of molds are made from alloy steels, and metal cores from high-carbon steels.

Permanent molds intended for iron and steel castings are largely cast pieces often put in service without further treatment. The working surfaces of molds designed for casting aluminum and magnesium

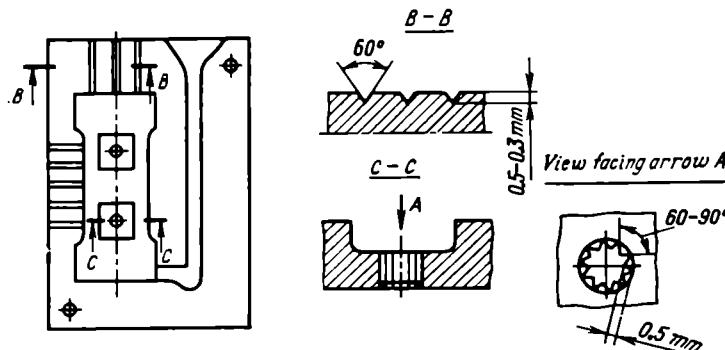


Fig. 197. Gas vents in permanent molds

Table 60
Compositions of Facings and Paints for Permanent Molds*

Alloy	Ingredients, %				
	Zinc oxide	Burned asbestos	Liquid glass	Talc	Boric acid
Aluminum	9.0	28.0	6.0	—	—
	—	—	3.0	—	—
Magnesium	—	—	2.7	8.0	3.2
	—	—	2.0	5.0	8.0
Iron	—	—	20-25	—	—
	—	—	4.3	—	—

* Facings and paints are applied on the working surface of molds heated to 200°C.
** To a paint density of 1.25 to 1.3 g/cm³.

alloys are machined to improve the dimensional accuracy and surface finish of as-cast products. Machining, however, adds to the cost of molds. Small molds are often made from steel forgings brought to size and desired surface finish by machining.

Permanent molds (Fig. 196) come in single-piece, horizontally split, and vertically split types. Molds with an intricate parting plane are also available. Single-piece (turnout)¹ metal molds are used for molding simple-shape parts without protrusions, horizontally split molds are intended for shallow and unimportant castings, and vertically split molds for small castings up to 75 kg in mass and also for flat and thin-walled core castings. Molds with a complex parting plane are used for intricately shaped castings.

In designing a permanent mold, particular emphasis should be placed on its venting in order to allow the gases to escape from the mold, for example, through risers and gas vents provided in appropriate places (Fig. 197). Vents are narrow channels, about 0.3 mm deep made on the mold joint surfaces or, sometimes, on the walls of working cavities, which serve to carry off the air and gases at the joints of separate parts of the mold.

Mold facings and paints. These are refractory dressings or coatings applied to the working surface of a mold and metal cores to protect it against the heat of liquid metal, increase the mold service life, control the cooling rate of the casting, and enable better filling of the

by mass						
Graphite	Coal	Clay	Ground chalk	Silica flour	Water	Type of coating
—	—	—	—	—	57.0	Facing Paint
					82.0	
—	—	—	—	—	82.5	Facing Paint
					85.0	
30-35	20-25	20-25	—	—	87.0	Facing Paint
	—	—	—	8.7	87.0**	

mold cavity. These refractory compounds include substances of low thermal conductivity, which impart the protective coat the heat-insulating properties. The coats decrease the rate of cooling of the melt and thus prevent the mold from excessive heating.

The refractory coating compounds are available in two general types, as *facings* and *paints* (washes). Facings are applied on molds in a layer 0.3 to 1 mm thick, generally once for a working shift, and paints practically every time after ejection of the casting.

The main purpose of the coat of paint is to prevent the facing from burning into the casting surface, raise the mold durability, and effect the desired heat conduction through the mold walls.

The compositions of facings and paints used in casting various alloys are given in Table 60.

Molds used for the production of bronze and brass castings are coated with washes. These are linseed oil, machine oil, fuel oil, and kerosene mixed with graphite, zinc oxide, talc, and other substances. Washes (whitenings and blackings) are applied on the surface of a mold after heating it to 100-150°C. To guard against chilling of the skin of iron castings, molds are given a composite coat consisting of the layers of refractory facings, paints, and acetylene black.

Sand-lined molds. The durability of molds designed for casting ferrous alloys is low; they are rigid and present difficulties when it is necessary to produce shaped castings of complex configuration.

The casting method which uses sand-lined molds obviates these difficulties. The process of lining of metal molds consists in the following (Fig. 198). The core shooter head forces a well mixed sand-resin compound (with 2.5 to 3% powdered bakelite) into the space between the working surfaces of the mold. The heat of the mold and pattern, both heated to 200-220°C, causes the sand-resin mixture to harden and form a strong coating 3 to 5 mm thick.

So that the protective coat will adhere properly to the mold surface, the latter must be rough. This is an advantage since the mold cavity need not be machined. To avoid the coat from sticking to the pattern, its surface is covered with a parting composition—a solution of synthetic heat-resistant rubber in white spirit. The cavities in castings are formed with the aid of common or shell cores. Unlike the usual facings and washes, this type of cladding gives a thicker coat which raises the durability of a mold. Besides, an enhanced heat resistance of the sand-resin coat decreases the cooling rate of metal and thus excludes chilling of iron castings.

The use of metal patterns, sand shooters, and various facilities for cleaning the mold surface from the remnants of the facing adds to the total cost of machines and molding equipment applied in this production process. In this connection, the method of casting in sand-faced molds is economically feasible in the large-batch and mass production of iron and steel castings. The automatic machines placed in

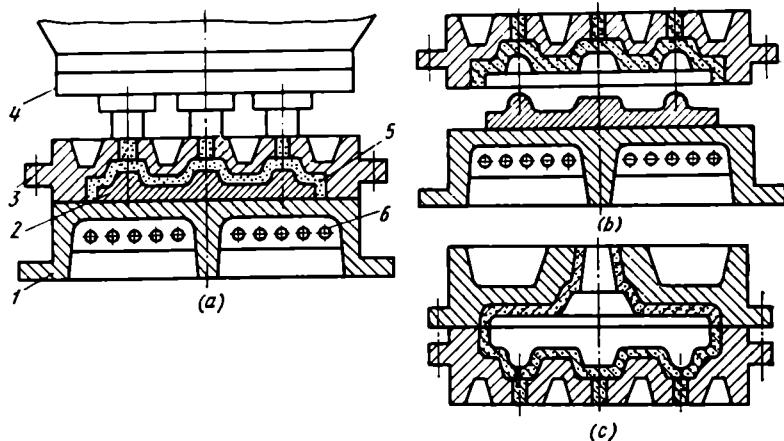


Fig. 198. Process of sand-facing a permanent mold

(a) sand shooting; (b) removal of mold from the plate; (c) mold assembly; 1—plate; 2—pattern; 3—mold; 4—sand shooter head; 5—sand facing; 6—heaters

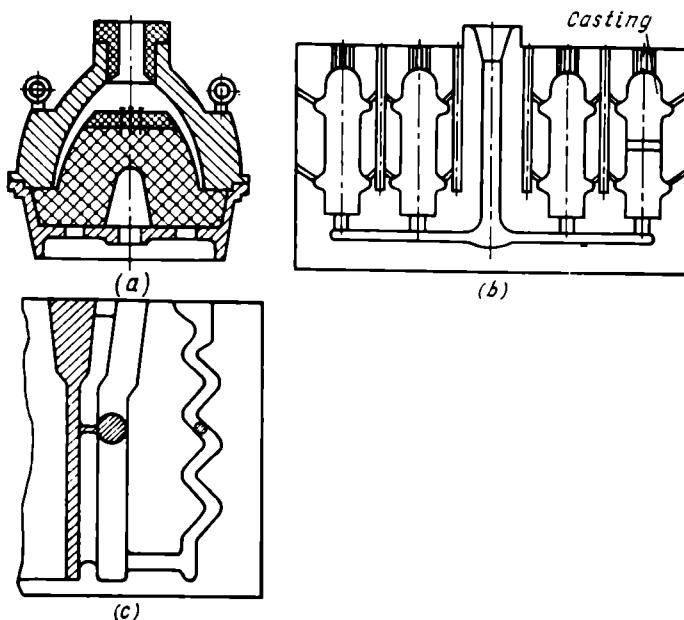


Fig. 199. Gating systems for running castings in permanent molds

(a) top gating; (b) bottom gating; (c) gating with wavy side sprue and slit gate

the production line to expedite the basic operations reduce the operating costs and make the process profitable.

Gatings systems. In evolving the design of a gating system for running castings from various alloys, the designer should rely on the basic design principles described above. At the same time, he must take into account the fact that the melt cools fast in metal molds, for which reason the cross section of gating elements here should be larger than is the case for sand molds, by approximately 25 to 33%. The gating channels should be as short as possible, without sharp angles and turns or abrupt variations in cross section. This helps minimize the thermal and hydraulic losses as the liquid metal flows through the gating system. The relation between the cross section of sprues, runners, and gates of the gating systems employed for casting light alloys should be the following:

$$F_s/F_r/F_g = 1/2/3 \text{ or } 1/2/6$$

The melt may run into the mold from the top, bottom, and on the side (Fig. 199). Top slit-type gates and wavy sprues are rather popular in gating aluminum and magnesium castings.

The gating systems for metal molds may be calculated by the same formulas as for sand molds.

1.3. CASTING VARIOUS ALLOYS

Casting of iron. Before pouring the metal into a permanent mold, its working cavity should be coated with a facing compound and paint. In every 100 to 200 pourings the mold is given a new coat of facing after cleaning the cavity from the old facing. The melt shouold be poured into a mold heated to 200-250°C since the cold mold is liable to cracking under the heat of liquid metal. To guard against the appearance of hard spots in iron castings, the mold cavity must be dusted with acetylene black applied on the paint coat before running the next casting. During the casting operation, the mold should not be heated over 400°C, otherwise this will cause cracking of its surface. The mold is commonly cooled in still air. Where good maintenance is implemented, the metal mold can stand 3 000 to 5 000 pourings.

The pouring temperature of iron ranges from 1 280 to 1 300°C depending on the mass and wall thickness of castings. It is very difficult to obtain chill-free castings up to 10 kg in mass and 12 mm in wall thickness. Such castings need annealing, excepting thick-walled simple-shape and unimportant cast pieces.

Heat treatment of iron castings is necessary to relieve internal stresses as well as eliminate the chilling effect.

Casting of aluminum alloys. The pouring temperature of aluminum alloys lies in the range from 710 to 720°C, so the mold does

not heat up as strongly as it does in casting of iron. The mold can stand as long as 50 000 pourings.

The rate of cooling and solidification of the melt in a permanent mold is much higher than in a sand mold, for which reason the permanent mold gives denser and finer-grained aluminum castings. This increases the strength properties of castings. For example, the tensile strength of permanent-mold castings rises 20 to 25% and elongation 1.5 to 2 times. Aluminum alloys exhibit good fluidity, which factor aids in the production of thin-walled permanent-mold castings of complex shapes. But since these alloys have high shrinkage, the need arises for installing large risers, sometimes exceeding the mass of the casting proper, to feed the thick sections and hot areas. Also, the gating system should provide for directional solidification of castings.

In molding thin-walled castings of intricate shapes and castings from alloys of decreased fluidity, the molds should be heated to 300-350°C. Running castings from alloys of good fluidity or producing thick-walled massive castings requires heating of molds to 200-250°C. The pouring temperature for an alloy depends on its chemical composition and the shape of a casting. When pouring aluminum alloys into permanent molds, the overheat above the liquidus curve commonly reaches 100-150°C. The enhanced temperature of pouring is necessary for thin-walled castings and also for castings made from alloys of poor fluidity. The pouring temperature for thick-walled castings should be lower to decrease the casting rejects due to porosity and shrinkage cavities.

Casting of magnesium alloys. Magnesium castings easily oxidize at the pouring temperature and thus are prone to ignite spontaneously. To keep an alloy against oxidation and inflammation, the working cavity of a permanent mold is dusted with sublimed sulfur before pouring. For the same purpose, the mixture of sulfur and boric acid is sprayed on to the stream of molten metal poured into the mold. After pouring, the surface of metal in the pouring basin and in the risers is also coated with the above mixture or common flux. These alloys are poured at an overheat above the liquidus of 130-180°C. Because most of the magnesium alloys show an increased volume shrinkage (up to 9%), massive risers are placed on the thick members of castings. To ensure that the risers give off less heat and produce a better feeding effect, it is well to set up in the mold hollow cores or ceramic sleeves which encase the risers and thus decrease the heat transfer. Most magnesium castings are heat treated to release internal stresses, stabilize the dimensions, and improve the mechanical properties.

Casting of copper alloys. Foundries use various grades of bronze and brass for the production of permanent-mold castings. The overheat temperature above the liquidus for copper alloys cast in perma-

ment molds is usually equal to 100-120°C and even reaches 200°C on molding thin-walled castings. Thick members of castings need risers and bobs which ensure proper feeding of the castings and compensate for shrinkage.

Casting of steel. Permanent molds produce castings from low-carbon, medium-carbon, and, sometimes, from alloy steels. The examples of cast parts include car wheels, gear wheels, rollers, and others. Since steel has a decreased fluidity and high shrinkage, the gating system should ensure the least thermal and hydraulic losses while pouring the metal into the mold. The gating systems use risers to provide for feeding of castings during solidification. The temperature of a mold in operation is commonly equal to 200-300°C. The pouring temperature of a steel depends on its chemical composition, but does not differ from that practiced in the production of sand-mold castings.

Steel castings are subjected to annealing to relieve internal stresses, and also to homogenizing, normalizing, and hardening to improve the mechanical properties.

1.4. PERMANENT MOLDING MACHINES

It is highly essential to mechanize the operations involved in the permanent-mold process, such as opening and closing of molds, setting and removal of cores, ejection of castings, coating of molds with the facing compound, cooling and heating of molds, and pouring. In use are special molding machines which open the molds both in the horizontal and in the vertical plane, and also semiautomatic rotary-table machines and conveyor-type permanent molding lines which perform the above operations.

Mechanized permanent-mold assemblies with programmed control find use for large complex-shaped castings whose production calls for permanent molds with several parting planes and a large number of metal cores ejected in various directions.

Universal or rotary-table molding machines and also *conveyor-type automatic molding lines* are designed to produce small or medium-size castings simple in shape. Permanent molding machines are commonly made complete with pneumatically or hydraulically driven mechanisms which open and close molds and eject castings.

Single-mold casting machines are available in two types, mechanized permanent-mold assemblies and universal permanent molding machines. Mechanized permanent-mold assemblies are usually employed in large-batch and mass production. They produce single-type castings or castings which vary little in design if the use of auxiliary mechanisms required to perform various operations offsets the expenditures.

Universal machines can cast a variety of parts whose dimensions correspond to the standard dimensions specified for the permanent molds. These machines have great production potentialities. It is

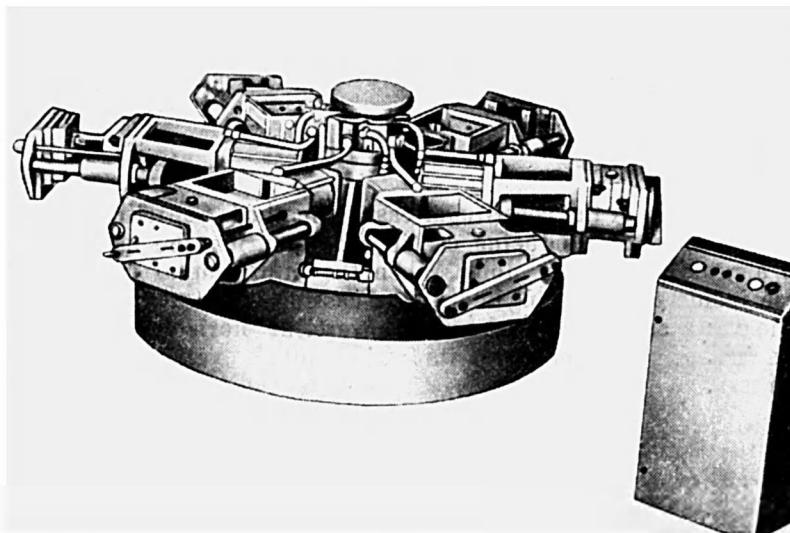


Fig. 200. Rotary-table permanent-mold casting machine

possible to mount on these machines vertically and horizontally split molds with metal and sand cores. The output of a single-mold casting machine ranges from 5 to 20 castings in an hour.

Rotary-table permanent molding machines are suitable for use in the large-lot and mass production of castings small in size and mass. The number of molds installed on the rotary table varies with the type of machine. Casting machine can have from 3 to 8 molds. Fig. 200 shows an automatic rotary-table permanent-mold casting machine designed to produce coreless castings from nonferrous alloys and iron in water-cooled molds. The mass of a casting with gates and risers can reach 10 kg.

As seen in the figure, the table carries six permanent-mold assemblies with vertically split molds placed on molding plates. The machine operates in response to a command sent from a control switch. The output can be as high as 300 castings per hour. In this respect, these multiple-mold machines are much more productive than single-mold machines.

Rotary-table machines are furnished with automatic metal pouring batchers.

Chapter 2. CENTRIFUGAL CASTING

2.1. GENERAL

The principle of the centrifugal casting method. Centrifugal casting is the method of producing castings by pouring the molten metal into a rapidly rotating mold. When the liquid metal is allowed to freeze inside the spinning mold, the casting results.

The mold can be rotated about a vertical, horizontal (Fig. 201), or an inclined axis, or about its horizontal and vertical axes simultaneously.

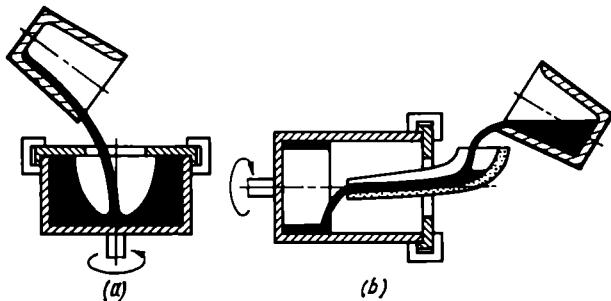


Fig. 201. Principles of vertical (a) and horizontal (b) centrifugal casting

The rotation of a mold about its horizontal or slightly inclined axis makes a suitable process for the manufacture of tubular products such as pipes, sleeves, and rings. The vertical process produces castings without central holes. These are shaped parts cast through a sprue in metal molds and also in sand molds.

The centrifugal method produces the highest technical and economic effect in casting the parts having the shape of bodies of revolution. The method can also be used to advantage in a number of cases for the production of shaped parts such as gears, turbine disks with blades, fittings, and so on. Centrifugal casting is a most effective method for the manufacture of iron pipes.

Pouring into a spinning mold and solidification of the casting in the mold rotating under centrifugal forces are the factors which determine the basic advantages of this casting method. These advantages include: (1) formation of hollow interiors in cylinders without cores since the rapidly turning mold causes the melt to move to the periphery under the force of rotation; (2) a minimum of metal required

for gates; and (3) solidification of the metal in a rapidly rotating mold, which results in a fine-grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity.

Along with the advantages, the method has disadvantages also resulting from the action of centrifugal forces. These disadvantages include: (1) increased segregation of alloy components during pouring under the forces of rotation, for which reason not all the alloys can be cast by the centrifugal method; (2) contamination of internal surfaces of castings with segregates and nonmetallic inclusions, which make it necessary to increase finishing allowances for subsequent machining of the internal surfaces; and (3) an inaccurate diameter of the inner surface of a casting.

Shaping of a casting under centrifugal forces. In the centrifugal process, a casting solidifies and cools in the centrifugal field of forces. The centrifugal casting cools both on the outside (the surface in contact with the mold walls) and on the inside (its inner surface) as a result of radiation and air convection. This gives rise to convection currents in the liquid metal: a cooler and, hence, denser metal moves from the inner surface to the mold walls, thereby effecting solidification of the casting in the direction from the mold walls to the inner surface.

But intensive cooling of the liquid metal due to convection and radiation from the inner surface leads to the growth of crystals which move toward the mold walls under the centrifugal forces. The crystals growing at the mold walls have an ample supply of the liquid metal, so that they grow in a direction more or less perpendicular to the melt motion. These features of solidification are favorable for the formation of a tight-grained outer surface of the casting. The light particles such as slag substances, nonmetallic inclusions, and gases move to the inner surface of the casting; this process also aids in producing a finer-grained structure and tends to give better mechanical properties. Alongside the above processes, the forces of rotation tend to segregate elements in accordance with their density in lead bronzes, aluminum bronzes, and hypereutectic silumins. This is also the case for irons where centrifugal forces cause the segregation of carbon, phosphorus, and sulfur. These influences adversely affect the mechanical and other service characteristics of the metal of castings.

The methods of calculation of the rotational speed of molds. The choice of the rotational speed of molds determines the strength, structure, and the distribution of slag inclusions, gas and shrinkage cavities, and segregates in castings. The rotational speed depends on the axis of rotation (vertical or horizontal), properties of the melt, and the diameter of the casting.

In determining the rotational speed of a mold, one should take into account not only the position of the axis of rotation, but also

the casting's internal surface distortion contingent upon the axis position. Experiments show that the optimal speeds which give high-quality castings differ with the kinds of alloy and, in general, depend on the casting dimensions, pouring temperature, and the mold temperature.

Where the ratio between the external radius r_1 and the internal radius r_2 of a casting is quite definite (for example, $r_1/r_2 = 1.15$), the formula given below may be quite useful for the calculation of the rotational speed of a mold:

$$n = \frac{K}{\sqrt{r_1}} \quad (25)$$

where K is a coefficient whose values are given in Table 61.

Table 61

Values of Coefficient K

Alloy	Density, g cm ⁻³	Axis of mold rotation	K	Casting
Iron	7.2	Horizontal Vertical	1 800-2 500 2 470-3 000	Tubes, sleeves Tubes
Steel	7.85	Horizontal	2 150-2 730	Hollow castings
Bronze	8.4	Vertical	3 400	Rings, sleeves
Aluminum alloy	3.10-3.65	Horizontal	2 600-3 500	Tubes, sleeves

The density of a rapidly turning metal, called the effective density, can be found by the formula

$$\delta = \frac{\rho \omega^2 r_1}{g} \quad (26)$$

where ρ is the melt density, g cm⁻³, ω is the rotational speed of a mold, s⁻¹, and g is the free fall acceleration, cm s⁻². The ratio $\omega^2 r_1/g$ is called the gravitational coefficient which shows how much the centrifugal forces increase the weight of the melt at the given rotational speed.

Professor L. S. Konstantinov has found that it is possible to obtain castings of high quality (good mechanical properties, adequate pressure-tightness, and other characteristics) from various alloys if the centrifugal force acting on the melt reaches the value at which its effective density becomes equal to 340 g cm⁻³.

According to professor L. S. Konstantinov, the rotational speed may be calculated with the formula

$$n = \frac{5 520}{\sqrt{\rho r_1}} \quad (27)$$

where 5 520 is the value of the coefficient, taken to be constant for all alloys, ρ is the density of a casting, and r_1 is the internal radius of the casting.

Formula (27) disregards the effect of the casting's wall thickness since it is of little significance for thin-walled castings. For thick-walled castings, however, this effect should be taken into account because the centrifugal force that acts on the outer surface of a casting reaches a value high enough to rupture the surface of metal adjacent to the mold wall and thus to cause a tear in the casting. Consequently, it is necessary to change the rotational speed of molds when casting thick-walled parts. At the beginning of pouring, the rotational speed of the mold is kept at a minimum, then, as the mold receives more metal and the layer of melt grows, the speed is raised to a maximum, at which, however, the surface layer should not be torn.

In casting shaped parts, one should choose such a rotational speed as to effect good filling of the mold and accurately reproduce the contours of the casting. As found from experiments, it is possible to obtain the best results if the rotational speed of a mold is so chosen that the peripheral speed of a casting point most distant from the axis of rotation is equal to 3-5 m/s.

The peripheral speed of any point of a rotating body may be calculated by the formula

$$v = \frac{\pi r n}{30} \text{ m/s}, \quad n = \frac{v \times 30}{\pi r} \quad (28)$$

where n is the rotational speed, rpm, and r is the distance from the point to the axis of rotation, m.

Let us determine the rotational speed of a vertical mold in a centrifugal casting machine (Fig. 202). Assume the peripheral speed is 5 m/s and the distance from the axis of rotation to the farthest point is 0.35 m. Substituting the respective values into formula (28) gives

$$n = \frac{5 \times 30}{3.14 \times 0.35} = 137 \text{ rpm}$$

2.2. MOLDS AND MACHINES

The centrifugal casting method employs both *metal molds* and *sand-faced metal molds*. The latter type has a sand lining made from sands of various compositions. The choice of the mold depends on the geometrical dimensions of a casting, its material, and the production quotas. It is more preferable to use metal molds in the produc-

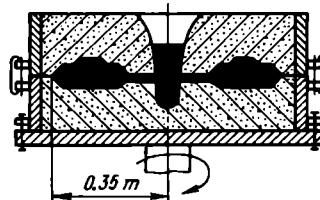


Fig. 202. Determining the rotational speed of a vertical mold in the centrifugal casting machine

tion of a large number of single-type parts which show no retarded shrinkage and have an outer shape allowing easy extraction of the casting from the mold. Sand-lined molds are preferable for castings in which the shrinkage retardation takes place and the outer surface of these castings causes difficulties in removing them from the molds. Also, these sand-lined molds can be used to advantage for the production of a small lot of iron castings without chilling.

A metal mold is heated to 150-200°C before pouring. After pouring, the mold is cooled to 150-200°C with running water in a bath or with water sprays, for which purpose the machines are equipped with special cooling systems. The service life of metal molds is short. For example, a mold used for pipes up to 50 kg in mass stands 400 to 500 pourings; a mold producing larger pipes can withstand merely 200 to 300 pourings. This is because intensive water cooling causes cracking of metal molds and thus decreases their durability.

Dry heat-insulating coats are applied to the inner surface of a mold to secure stable thermal conditions, increase its durability, and, besides, produce iron castings free of chill. The dry coats used for the purpose consist of powdered refractory materials such as quartz sand and phosphate flour applied on the working surface of a mold. A coat of powder is held on the mold surface under the action of centrifugal forces. The dust is commonly introduced into a mold through a pouring trough as the mold spins at a constant speed.

Powdered coating decreases the rate of cooling of a casting, but cannot overcome completely the chilling effect, and, besides the iron casting surface becomes slightly rough, which makes it necessary to increase the machining allowance to not less than 4 mm. Nevertheless, the durability of powder-coated molds increases sevenfold. In casting cylindrical iron sleeves 10 to 12 mm in wall thickness and up to 100 mm in diameter, the mold can produce as many as 3 500 iron castings.

Sand-faced metal molds use the lining prepared from common molding and core sands, and special sand mixtures. Dry-sand molds are applicable for casting pipes and shaped products. The lining is formed by packing the sand on to the metal mold surface on special squeeze-type screw machines, or by rolling on the coat of sand to the mold surface, and also by the sand blowing method.

Centrifugal casting machines come in driving-roller types and spindle types. Spindle-type horizontal-mold machines are suitable for casting short sleeves, shell cases, and rings; horizontal-mold roller-driven machines produce pipes; and machines with the molds rotating about a vertical axis find use in the production of shaped castings.

Figure 203 shows a spindle-type centrifugal machine for casting sleeves and shells up to 350 mm in length and 300 mm in diameter. The mass of a casting can be as high as 100 kg.

The machine consists of a bed, a pouring trough 1 with a spout passing through a hole in a hinged door 2, a metal mold 6 inside a casing 4 and protective guard 5 with a water cooling arrangement, a hollow shaft 8 rotating in roll bearings on supports 7, and belt transmission with a step pulley 10 for transferring power from an electric motor 11 to the spindle (hollow shaft).

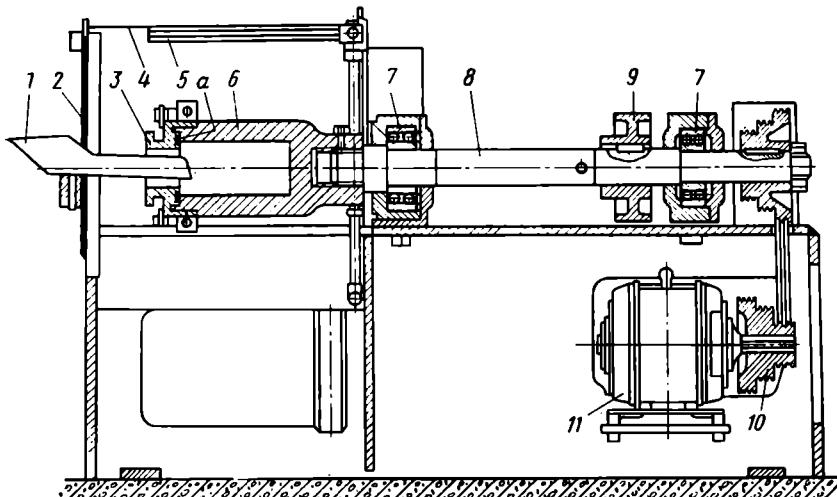


Fig. 203. Spindle-type horizontal-mold centrifugal casting machine

As seen from the figure, the mold is fastened to the end of the driving shaft, which can rotate at a speed of 625, 1 000, and 1 610 rpm. A block brake 9 can stop the rotation of the mold whenever necessary. A cap 3 fixed to the mold with special nuts has a hole on the inside, whose diameter is equal to the internal diameter of the casting, and a circular groove *a* stuffed with a refractory material to protect the end face of the casting against chilling.

Chapter 3. DIE CASTING

3.1. GENERAL

The essence of the process. Die casting is a modified permanent-mold process that uses excess pressure instead of gravity to inject molten metal into the die cavity. The maintenance of high pressure during solidification of the melt in a metal mold (die) is beneficial for producing high-quality castings. A low surface roughness and high dimensional accuracy of the die cavity enables the production of accurately dimensioned parts whose surfaces practically need no machining. Moreover, the melt injected under pressure quickly takes the shape of the mold.

Various die-casting machines are available, which perform basic production operations.

Figure 204 illustrates schematically a horizontal-plunger cold-chamber die-casting machine. A movable and a stationary part of die 4 are respectively fastened to a moving platen 3 and to a fixed platen 5 with bolts and clamps. The positioning and centering of the die parts are checked by opening and closing the die with a locking mechanism actuated by a hydraulic cylinder 1.

The casting process begins with heating of the die, pressure sleeve 6, and injection piston, or plunger, 7. For this the operator pours the melt into the die a few times. The castings produced at this stage are mainly defective. The heating temperature depends on the pouring temperature of the melt injected into the die. The heating being over, the operator coats the die cavity with special greases, exercising particular care when coating the friction parts of the die, horizontal sleeve 6, and plunger 7. He then opens and closes the die several times without pouring the metal to check the die for proper operation. After bringing together the movable and stationary parts of the die and locking them with mechanism 2, the machine is made ready for operation. The melt is poured from the ladle into the sleeve (Fig. 205a), and then a pressure mechanism 8 is actuated to put in motion the plunger 7 (Fig. 205b), which forces the molten metal from the sleeve into the die cavity (Fig. 205c).

The metal is allowed to solidify and cool, following which the die is opened to eject the finished casting (Fig. 205d).

Die casting is a most progressive method for the manufacture of castings from nonferrous alloys such as zinc-base, aluminum-base, magnesium-base alloys, and brasses. This method finds wide application in the instrument engineering, automotive-tractor industry, electrical engineering, and in other industries.

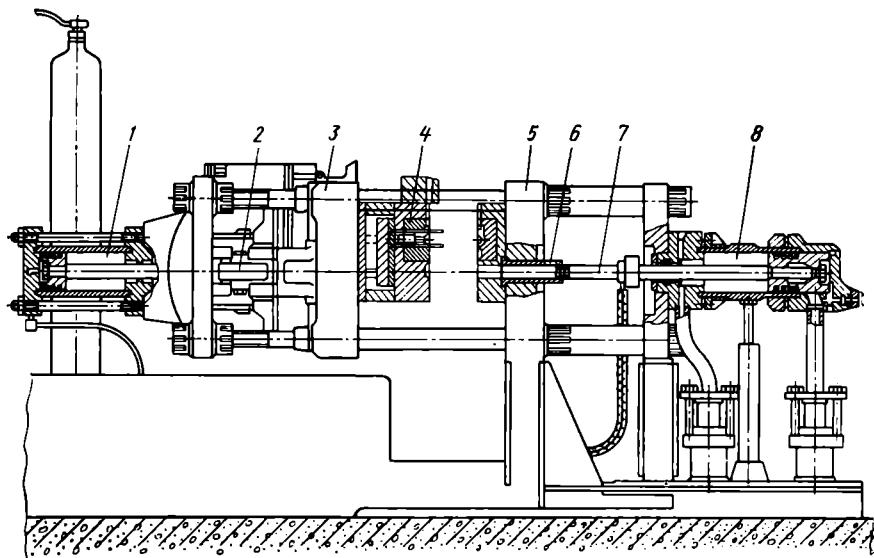


Fig. 204. Horizontal-plunger cold-chamber die-casting machine

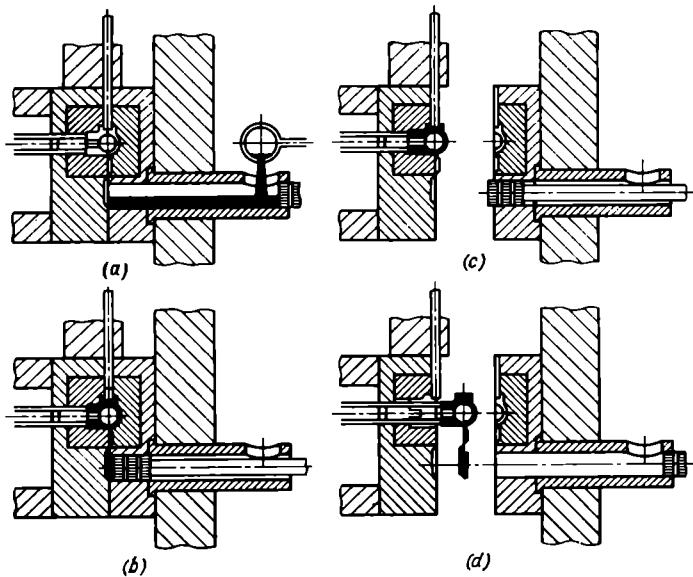


Fig. 205. Basic die-casting operations

The advantages of die casting include high outputs and the possibility of producing intricate thin-walled castings with a minimum of stock left for machining. Also, as-cast parts have a clean and smooth surface, and the metal shows a fine-grained structure and high mechanical properties.

The die casting process can produce highly intricate castings with the walls as thin as 0.8 mm, which require little machining. Castings are made to the fifth and, sometimes, to the third class of accuracy; the surface finish corresponds to the fifth or sixth class. The stock left for finish machining does not exceed 0.8 mm in thickness.

The process is adaptable to complex automatization, starting with pouring of the melt into the sleeve and ending with cutting of gates and fins. The automatic die-casting process raises the production efficiency and improves the quality of castings.

The shortcomings of the die-casting process include: a high initial cost of dies whose manufacture calls for complex and lengthy operations; difficulties involved in the production of castings with intricate cavities; gas and air porosity in castings; a restricted range of alloys adaptable for die casting; and the limits the casting machine power places on the size and mass of castings.

The die-casting process is economically possible in the long-run and mass production. However, standardized dies, and universal built-up dies enable us to use a small number of standard blocks and die parts and to assemble the appropriate die blocks in a great variety of constructions, up to 5 000. What is necessary to do in this case for the construction of the desired die is to prepare inserts and cores which would adequately form the shape of a casting and its cavities. Such an approach makes economically feasible the production of small lots of castings and expands the field of application of this shaping process.

Shaping of a casting. The mechanical properties, density, pressure-tightness, dimensional accuracy, and surface finish — characteristics that determine the quality of a casting—greatly depend on how the metal fills the die and solidifies into the desired shape. A high rate of cooling of the melt in a lining-free molding die calls for injecting the melt into the die at high speeds, 1 to 35 m/s. There are two main principles, laid down by professor A. I. Vejnik, which form the basis of the methods for injecting the melt into dies.

The principle of maximum friction consists in that the melt flows into the die through a thin nozzle 0.5 to 1.5 mm across at a very high speed, over 10-15 m/s. The friction loss in the nozzle is at a maximum. Such an injection method permits the production of thin-walled large-sized castings of intricate shapes. This method, however, is not free of a drawback. The matter is that the air, vapors, and gases evolved during grease decomposition have no time to escape from the die and thus get into the melt, forming in the casting small gas and

shrinkage pores, which affect its pressure-tightness. The thin sprue solidifies faster than the casting, so the static pressure of the injection plunger does not practically act on the solidifying metal. The high rate of metal cooling promotes a fine-grained structure and tends to give rather high mechanical properties despite the presence of pores in the casting body. The castings produced by this method cannot be heat treated since the gases would expand under heat and deform the casting, affecting its dimensional accuracy.

The principle of minimum friction lies in that the die receives the melt through a massive sprue; the loss due to friction of the metal against the sprue wall is minimum. The metal fills the die at a lower speed than is the case with the above-described method. That is why it is difficult to obtain here thin-walled intricately shaped castings; the method is best suited for the production of thick-walled castings. The sprue solidifies at the same time as the casting or a little later. That is why the injection plunger is able to exert static pressure on the solidifying casting. The method produces tighter-grained parts with high mechanical properties. All the same, this method does not fully obviate the danger of the formation of gas cavities.

There are several ways of increasing the density, pressure-tightness, and mechanical properties of castings: by maintaining a vacuum in the die cavity, additionally pressing the metal during solidification of the casting, forming an oxidizing medium in the die, and casting alloys in the semifluid state.

Vacuum die casting. A vacuum built up in the die cavity permits decreasing the porosity in castings and thus offers the opportunity of producing castings whose walls can be 30% thinner than the walls of castings made by the common die-casting process. However, the equipment required to keep the die cavity under vacuum complicates the design of a casting machine and decreases somewhat its output.

The oxygen process. In this method, a special device forces oxygen into the die cavity and pressure chamber to replace the air and the gaseous products of the grease. On injecting the melt into the die cavity, oxygen reacts with the metal, giving rise to a vacuum, while the minute oxide particles uniformly disperse over the bulk of the casting which becomes dense and rather impermeable. Fine-dispersed oxide inclusions do not reduce the mechanical properties. The casting obtained by this method can be heat treated to improve the properties. The oxygen process does not lengthen the casting cycle, nor reduces the machine output capacity.

Die casting with additional pressing. This method is also aimed at increasing the density of castings and decreasing the gas and air porosity. The production process favors the conditions at which static pressure acts on the metal from the moment the melt fills in the die cavity up to the moment of complete solidification of the

casting. Such an influence of pressure on the casting takes place to a certain extent under common conditions of die casting too, but this effect is of short duration since the sprue solidifies too quickly. Consequently, the essential condition that would make pressing effective is to implement a metal solidification procedure according to which the metal in the sprue and the chamber could solidify longer than the metal of the casting. In this case it would be possible to transmit pressure from the injection plunger to the solidifying casting, supply the melt to the casting, and thus decrease the total volume of gas, air, and shrinkage cavities and increase the casting density.

In common use are special pressure step-up devices (boosters) which build up a pressure acting on the melt in the chamber to 490 MPa (5 000 kgf cm⁻²).

Die casting of alloys in semifluid state. As with the above methods, the aim of this method is to increase the density and pressure-tightness of castings. The method uses the property of alloys to remain fluid in the temperature range characteristic for the liquidus-solidus (liquid-solid state) if the alloys are intensively mixed. The alloy prepared in a melting furnace fitted out with a mixer is poured into the sleeve of a casting machine and injected into the die cavity. Since the alloy is poured at a temperature below the liquidus, its shrinkage is smaller and the casting is less prone to develop shrinkage porosity. The die is usually filled with metal under low friction conditions and at relatively low speeds (up 7 m/s), which aids in decreasing the gas and air porosity and results in dense, impermeable castings. Besides, owing to lower temperatures of alloys poured in the semifluid state, the parts of the pressure chamber and die wear to a lesser degree and the metal does not weld up to the die parts. This method is used for the production of critical castings.

3.2. PRESSURE CASTING DIES

Molding dies are made from special high-temperature chromium steels and tool carbon steels. The durability (life) of a die is that property which makes the die suitable for repeated use. This characteristic is expressed through a number of sound castings the die is able to produce.

A die made from heat-treated high-temperature chromium steel can give from 60 000 to 200 000 aluminum castings and from 5 000 to 50 000 bronze castings. The die, as shown in Fig. 206, consists of two main parts, a stationary part (called a cover die, or fixed die) and a moving part (called an ejector die, or movable die) which has an arrangement for ejecting the casting. The cover die is fastened to the front platen (fixed plate) of a casting machine on the side of the pressure chamber. The ejector die is fastened to the sliding plate (moving platen). The casting is always positioned in that part of the die

which has a greater number of projections forming the internal contours and undercuts in the casting.

A replaceable insert 1 forms working portion of the cover die that comes in contact with liquid metal. A bush 4 acts as a sprue. The cover die insert 1 and the bush 4 are fixed to a plate 23 with slides

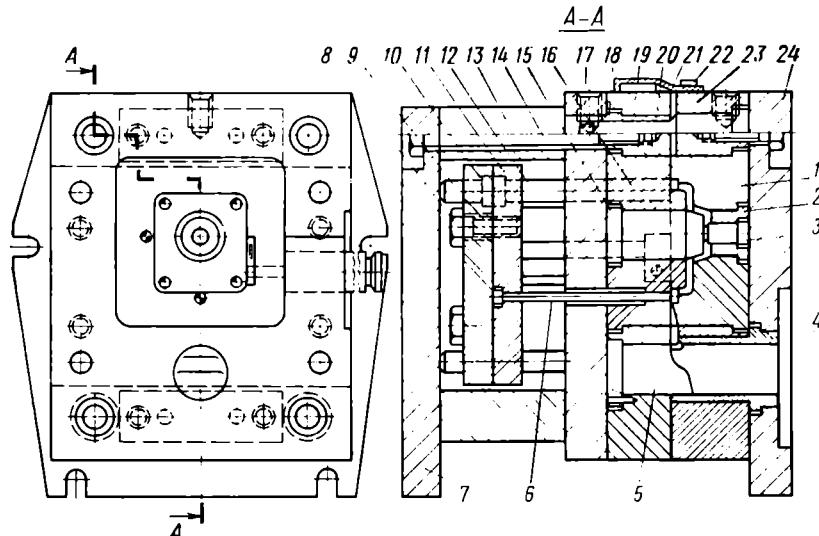


Fig. 206. Design of a pressure casting die

20 which set the die parts in a definite position during the operation. A shield 21 which serves to protect the operator from metal sprays is attached to the plate 23 with screws 22. This plate is provided, if necessary, with channels for die cooling and with vents to allow the air and gases to escape from the die cavity. Some cores which serve to form cavities in the casting are set up in the cover die. The insert 1, sleeve 2, and core 3 are secured in place with a backing plate 24.

An insert 16 mounted in a plate 19 forms the working portion of ejector die. A distributor 5 causes the stream of metal to flow in the right direction. Detachable guide sleeves 18 are inserted into the holes for slides 20. A core 15, whose working portion lies at a right angle to the die joint, is made fast to the die. Dies are often provided with movable and detachable cores which are ejected by special mechanisms.

Inserts and cores are fitted on the sliding plate and fixed in position with a backing 17. The sliding plate and the backing are fastened to a pedestal with bolts 14. The pedestal consists of a support 13 and plate 7.

The casting is removed from the movable die with ejector pins 6. The ends of ejector pins should be 0.3 to 0.5 mm above or below the shaping surface of the die. The ejector pins 6 are fixed to plates 10 and 11 joined together with bolts 8. The pins are shifted to the position they must occupy in the closed die with counterejectors 12. Stops 9 hold the pins in place during injection of the metal into the die. The working surface of the die should be made to the third class of accuracy. The fixing dimensions of mating parts should conform to the second or third class of accuracy. The plates of a movable die, cover die, and ejector pins, and also ejector pins themselves, cores, distributors, and other parts are standardized. The inserts of a cover die and ejector die are made replaceable.

To increase the durability of a die, its critical parts are heat treated. Besides, provision is made for cooling the working surfaces of the die with air and its walls with water pumped through the channels drilled in the walls.

3.3. DIE CASTING MACHINES

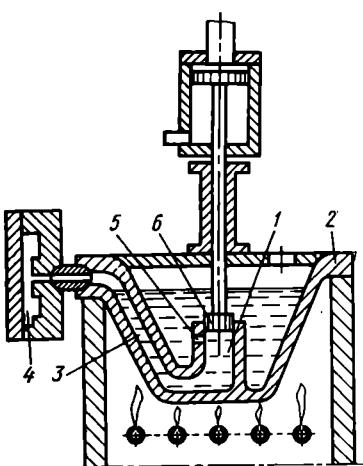
Two main types of die-casting machines are available, the hot chamber and the cold chamber type.

Hot-chamber die-casting machines (Fig. 207) are used for casting low-melting alloys based on zinc, lead, and tin. A pressure chamber

1 is submerged beneath the pool of molten metal contained in a pot 2. The metal fills the chamber through an intake 5 which closes as plunger 6 (piston) moves downward to force the melt through a heated channel 3, called the gooseneck, into a die cavity 4. After solidification of the casting, the piston returns to its original position and the molten metal left in the gooseneck flows off into the die, the ejector pin pushes off the casting, and then the die closes to repeat the cycle. Hot-chamber die-casting machines have shortcomings: the piston and pressure chamber quickly go out of order because of the prolonged contact of these working elements with the molten metal. For the same reason, these machines cannot operate at high die-casting pressures.

Fig. 207. Hot-chamber die-casting machine

In the last years these machines have come into use for the production of castings from magnesium alloys.



Cold-chamber die-casting machines produce castings from the alloys based on aluminum, copper, and magnesium. The molten metal is supplied from the furnace to a pressure sleeve with a metering ladle or a special automatic feeder. The pressure chamber is so located that the plunger can reciprocate either vertically or horizontally. The machines are correspondingly divided into the vertical

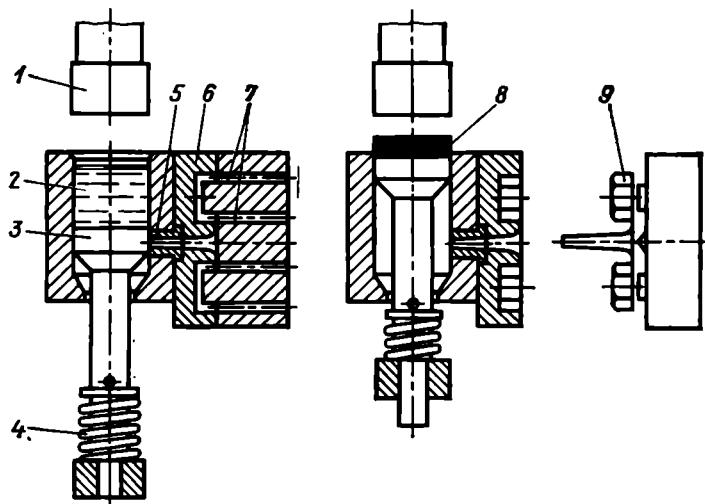


Fig. 208. Vertical-plunger cold-chamber die-casting machine

plunger and the horizontal plunger type. Horizontal-plunger cold-chamber die-casting machines are most popular because they are capable of producing high pressures.

In modern cold-chamber machines designed to cast aluminum and copper alloys, the die-casting pressure reaches 31.4 to 177 MPa (300 to 1 500 kgf cm⁻²). Cold-chamber die-casting machines are available in which the die-casting pressure can be as high as 186 MPa (2 000 kgf cm⁻²). The scheme of a horizontal-plunger cold-chamber machine is shown in Fig. 204. The principle of operation of a vertical-plunger cold-chamber machine is illustrated in Fig. 208. A measured quantity of liquid metal is ladled into a pressure chamber 2 (a well), and a plunger 1 forces the melt through a sprue 5 into a die consisting of a movable die block 7 and fixed die block, 6. A counter-plunger 3 with a spring 4 shears a metal residue 8, or slug, from the sprue and ejects it from the well 2. The ejector pins then push off the finished casting with gates from the movable die 7.

Modern die-casting machines are equipped with *automatic pouring arrangements*. They operate in combination with temperature-

controlled holding (maintaining) furnaces which automatically meter out a desired quantity of metal to be poured into the die.

Mechanical feeders have a ladle of required capacity. The ladle furnished with a hydraulically driven mechanism scoops the required portion of liquid metal from the holding furnace and conveys it to the die-casting machine for pouring the metal into the pressure chamber. These feeders are simple in design, but suffer from the disadvantage that the ladle often becomes inoperative.

Vacuum feeders operate on the principle of suction under vacuum of a certain quantity of melt from the holding furnace. They usually operate integrally with vacuum die-casting machines.

Electromagnetic feeders have no moving parts, which is an advantage. The feeder depends for its operation on the interaction of a current flowing through the melt with an external magnetic field. The electromagnetic forces act on the melt and cause it to flow in a direction determined by the left-hand rule. These feeders find increasing uses.

Pneumatic feeders are easily controllable devices which can accurately meter out the melt relatively free of contaminants and secure a minimum loss of heat. A feeder operates in combination with a resistance furnace sealed with a lid. In operation, the compressed air supplied through a valve to the feeder forces a strictly measured quantity of melt to flow through a nozzle into the chamber of the die-casting machine. The feeder meters out the melt to an accuracy of $\pm 5\%$.

Mechanization and automatization of the die-casting process decrease the casting wastage because the operator can readily adjust the working parameters if they deviate from the preset values. The other points in favor of automatization are an increased labor productivity and improved working conditions. In the completely automated die-casting process, machines and mechanisms perform the following operations: grease the die, the pressure chamber, and the injection piston; regulate the heating and cooling systems of the die; supply the melt to the chamber, eject castings and convey them to the trimming press to remove flash and to the cutter to remove sprues and gates, and then deliver the finished castings to the batch bin.

3.4. GATING SYSTEMS AND OPERATING CONDITIONS

Alloys used in die casting. These are mostly aluminum alloys which combine good physical and mechanical properties with adequate technological properties. They show sufficient strength and plasticity at high temperatures, good castability, and stability of the chemical composition on long-term holding in maintaining fur-

naces. Apart from aluminum alloys, other types of alloys based on magnesium, zinc, and copper, are suitable for pressure die casting.

The design of a casting must satisfy service requirements, be technologically feasible, take into account the properties of the alloy to be cast, and the types of machining. The wall thickness of ribs in the casting must be the same in all its sections to preclude gas, air, and shrinkage porosity. Thin-walled die castings feature a fine-grained structure and high density. It is possible to increase the rigidity of a casting with additional ribs whose walls can be eight-tenth or nine-tenth as thick as the casting walls.

Gates and vents. The gating system must provide for quiet running of liquid metal into the die. The cores and protrusions must not cause whirling of the metal flow. Vents must allow free escape of the air and gases from the die. The gates must be positioned in such a manner as to exclude counterflows, impacts of the metal stream against the walls of the die or cores, sharp turns, expansion of the stream, and so forth.

In vertical-plunger cold-chamber die-casting machines (see Fig. 208), the gating system consists of a sprue, runner, and gate. In machines of the horizontal-plunger type (see Fig. 204), the gating system includes a sprue and a gate. A short path of metal flow in the gating system of the horizontal-plunger type machine is its basic advantage. A metal residue, called a slug, may in a way be considered as part of the gating system.

The venting system consists of channels in the form of slits 0.05 to 0.3 mm deep and 5 to 20 mm wide. The vent may communicate with a die cavity directly or through a *flush channel*. The latter serves to drain the first portions of liquid metal contaminated with air, oxides, and grease. Vents should be arranged at the sites where the air and gases are likely to accumulate in quantities.

There are three types of gating systems as regards the positioning of the sprue.

Top gating with a drop sprue. As seen in Fig. 209a, the sprue directly enters the die cavity. The sprue fills the die in a continuous stream with a minimum of heat and hydraulic losses. This type of gating is suitable for running castings without holes in the center and commonly finds use for casting semifluid alloys at a low speed of pouring.

Top gating with a central sprue (Fig. 209b). Such a positioning of the sprue enables decreasing the dimensions of the die. It is largely applicable for running frame-type castings.

Gating with a side sprue (Fig. 209c). The metal flows from the sprue and over the contour of the casting. This gating system is often used in single-cavity and multiple-cavity dies.

The methods of calculation of gates rely on experimental and working data. For example, a method developed by engineer N. A. Shu-

bin can be used to calculate the gates for thin-walled castings 2.5 to 5 mm in wall thickness and up to 500 mm in size. The cross-sectional area (in mm^2) of a gate may be found by the formula

$$f = \frac{m}{\rho K} \quad (29)$$

where m is the mass of the casting, g , ρ is the density of the alloy pour-

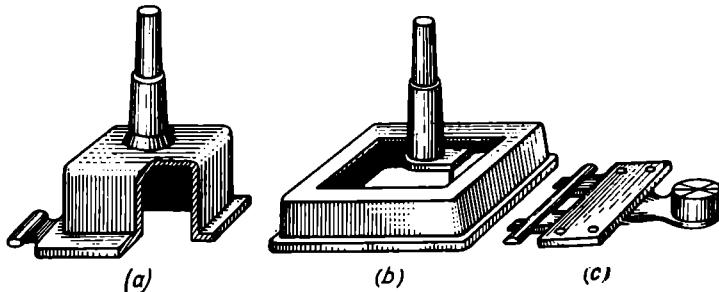


Fig. 209. Types of gating

ed, g cm^{-3} , and K is a coefficient depending on the time and speed of pouring, the casting shape and the kind of alloy (Table 62).

Table 62

Values of Coefficient K for Castings Made of Various Alloys

Shape of casting	Alloy			
	magnesium	aluminum	zinc	brass
Simple	7.32	6.09	2.16	1.89
Complex	6.05	5.25	1.87	1.63
Very complex	4.78	4.41	1.57	1.37

Temperature conditions chosen for the die-casting process depend on the kind of alloy and the shape of a casting. The temperature of heating of dies before injecting zinc alloys, aluminum alloys, and brass is respectively 120 to 160°C, 180 to 250°C, and 280 to 320°C. The pouring temperature for an alloy poured into a cold chamber of the machine must be 10 to 20°C above the liquidus.

Die-casting pressures at which the machines should operate depend on the kind of alloy, wall thickness and shape of the casting. Practical considerations and recommendations are the main criteria which determine the choice (Table 63).

Table 63
Die-Casting Pressure, MPa (kgf cm⁻²)

Casting wall thickness, mm, not over	Shape of casting	Alloy			
		zinc	magnesium	aluminum	brass
3	Simple	44 (450)	49 (500)	34.4 (350)	59 (600)
	Complex	44 (450)	54 (550)	44 (450)	69 (700)
	Very complex	49 (500)	59 (600)	49 (500)	78.5 (800)
6	Simple	54 (550)	69 (700)	59 (600)	88 (900)
	Complex	59 (600)	78.5 (800)	64 (650)	98 (1000)

3.5. LOW-PRESSURE DIE CASTING

The principle of this die-casting method (Fig. 210) comes to the following. The pressure of air or gas forces the melt in a pot 2 of a holding furnace 1 to rise through an injection tube 4 submerged beneath the bath into a metal mold 5 set up on a lid 3 of the pot. The mold (die) has a core 6 to shape a cavity in the casting. As the casting solidifies, the pressure in the pot is released by bleeding the gas into the atmosphere. The metal residue flows from the tube 4 into the pot. The method is suitable for casting parts from aluminum alloys, magnesium alloys, copper alloys, and, rarely, from steel. What makes this method attractive is that it requires a smaller amount of metal for gates and thus ensures a higher casting yield.

Shaping of a casting. In order to produce a sound casting, the metal should fill the die in a continuous laminar stream at a relatively low pouring speed. Such conditions are favorable for the formation of castings free of gas cavities and oxide spots. On the other hand, low speeds of metal flow may cause misrun in thin-walled castings. It

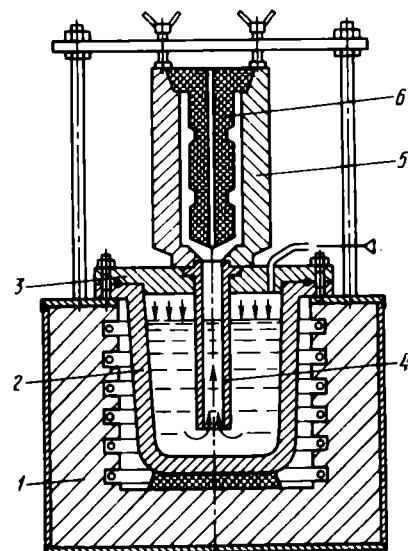


Fig. 210. Low-pressure die-casting unit.

is thus important that the hydrodynamic conditions should be consistent with the thermal conditions during the injection of the melt into the die. *What distinguishes* the process of shaping of a low-pressure die casting is the possibility of initiating directional solidification. Since the lower cross sections of the die cavity closer to the injection tube let pass a larger quantity of metal than its upper cross sections, there is a difference in temperature between the lower and upper portions of the casting. For this reason, it is well to position the massive sections, which require feed metal to compensate for shrinkage, at the bottom of the die and connect them with the injection tube through thick gates; thinner sections which do not need feed metal during solidification can be located at the upper part of the die.

A hydraulic impact that may arise in the die at the end of injection is conducive to mechanical penetration of metal into core sand in castings made with the use of sand cores. On the other hand, the static pressure acting on a casting as it solidifies causes the solid skin of metal to press against the die walls, with the result that the rate of solidification grows and the casting obtains a tighter-grained structure.

Dies. This method largely uses metal molds, called dies. Intricate cavities of castings are formed with the aid of sand and shell cores. These cores must be sufficiently strong to withstand the pressure of liquid metal. The design of the core prints of a core must be such as to preclude its shifting under the action of metal. A die must be provided with adequate vents to enable the gases and air to get out quickly from the die cavity during metal injection. Vents, plugs, grooves, and other elements are made here in the same manner as in permanent molds.

Casting conditions. Thermal and hydrodynamic conditions depend on the kind of alloy and the design of a casting. It is necessary to strive to fill the die at a minimum of overheat, but sufficient enough to avoid misrun. The temperature of dies before metal injection is usually the same as that specified for permanent molds. In casting aluminum alloys, the choice of the speed with which the melt should rise in the die depends on the shape and wall thickness of a casting, and alloy properties. This rate does not commonly exceed that specified for permanent molds.

Chapter 4. INVESTMENT CASTING

4.1. GENERAL

The principle of investment casting. In this method of casting, patterns are prepared from such materials that can be readily melted or burned to produce a single-part mold. When liquid metal is poured into such a mold, a high-precision casting results (Fig. 211). That is why this casting process also bears the name of precision casting. Patterns are most often made from easily meltable waxlike materials.

An expendable pattern 1 is cast in a master die, or permanent mold, 2, either by pouring or by injecting a pattern mixture in the die cavity. The patterns are then built up into a pattern block 3. Next the entire block, or assembly, is given a refractory coat 4 by dipping it in a refractory slurry containing, for example, silica flour, corundum, and a binder (a colloidal solution of silicon dioxide). This coat is dusted with a coarse-grained refractory material 5, such as sand of fireclay, and then dried. In the course of drying, the solvent evaporates and the colloidal solution of silicon dioxide passes from the unstable state (sol) to the stable state (gel). The gel binds together the grains of the refractory and imparts strength to a shell 6. The shell is then coated with a refractory suspension and again dusted with a grainy refractory. The finished shell that envelops the pattern block may consist of 4 to 6 refractory layers. The pattern compound can be melted from the shell by dipping it into hot water 7. The shell is now placed into a heat-resistant steel flask 8 which is then filled with the investment—dry quartz sand. The flask is vibrated to assure a sound mold.

Next the flask is passed through an oven 9 and preheated to 900–1 000°C, the object of preheating being to remove moisture from the shell and the traces of the pattern compound. Molten metal 10 is then cast into the hot mold. After cooling of the castings, the shell is stripped quite readily from the outer surface, but is held fast in holes and cavities of the castings. These residues of the shell can be removed by alkalization. An alkali reacts with the shell material, forming the solution of sodium silicate. After alkalization, the castings are rinsed in hot water and then dried, following which the castings are heat treated and inspected for quality.

The process of investment casting is particularly useful in the manufacture of intricately shaped components with walls up to 0.5 mm thick, primarily from steel and high-temperature alloys which are difficult to machine. The advantages of investment casting are: the

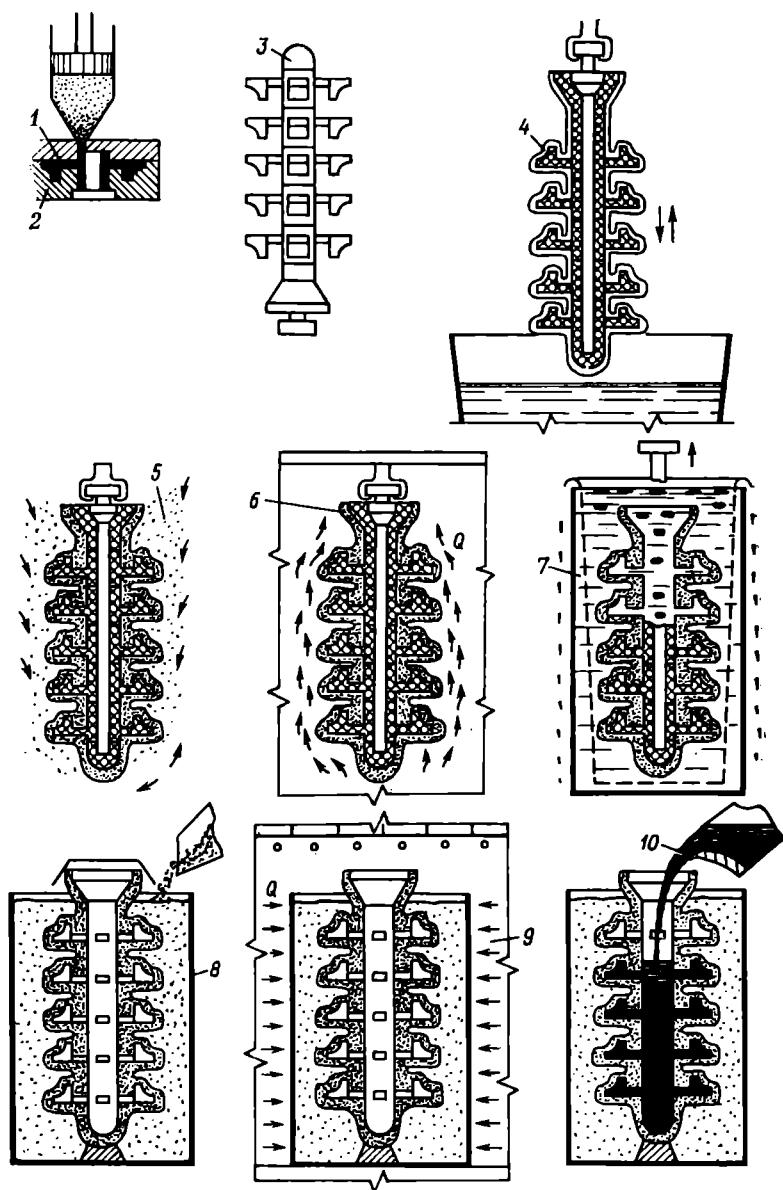


Fig. 211. Production stages involved in investment casting

production of parts from alloys which are not amenable to mechanical treatment; a high dimensional accuracy of castings, up to the 4th class, and good surface finish, up to the 6th class, which in a number of cases obviates the need for machining; and the manufacture of machinery parts which would have to be built up from separate pieces if common casting methods were used.

Investment casting is adaptable to the piece (pilot), batch, and mass production. The economic and technical usefulness of this method depends on the range of products being cast. This method is not advantageous for the production of small complex-shape castings, large castings of high dimensional accuracy and surface finish in the as-cast state, and also castings from hard-to-machine alloys.

4.2. PRODUCTION OF PATTERNS

Master dies for patterns. Investment patterns are cast in master dies (Fig. 212). The dimensional accuracy and surface finish of master dies determine the accuracy and surface finish of castings.

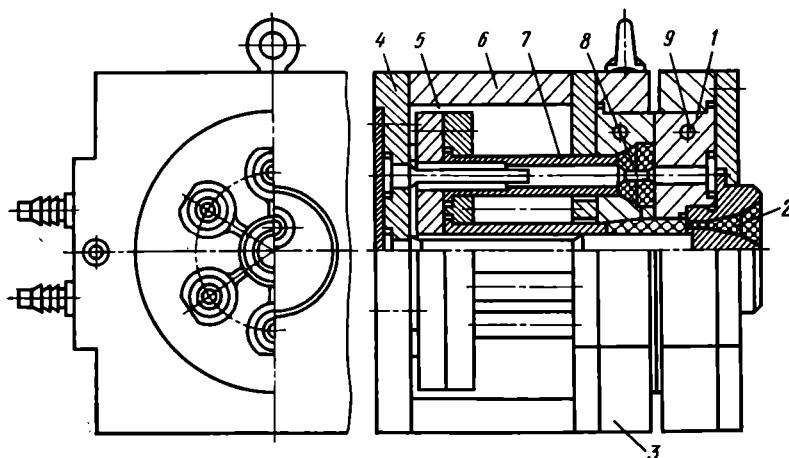


Fig. 212. Master die for the production of a set of investment patterns

Master dies are made in steel if there is a need to make them serviceable for thousands of injections. Where the runs are short, it is possible to make permanent molds from aluminum alloys, lead-antimony alloys, gypsum, epoxy resins, and from some species of hardwood.

Master dies are prepared by machining, by casting with the use of a master pattern, and by electrodepositing metal on a master pattern.

In mass and large-batch production, master dies are made of steel by machining. The vertically split master die for six patterns (see Fig. 212) consists of a movable die 1 with a bush 2 and a fixed die 3. The fixed die block is made fast to a plate 4 with supports 6. Cores 8 attached to the plate act as guides for sliding ejector pins 7 secured in a plate 5. The die inserts which serve to form a pattern have water-cooling channels 9.

On opening the die, the patterns remain in the fixed die block; as soon as the movable die block travels a distance exceeding the pattern height, the pins eject the patterns from the die. Such dies are mounted on rotary-table automatic machines.

The dimensions of the working cavity of a die are calculated with due regard for the shrinkage of a pattern compound, deformation of the ceramic shell during its calcination, and the shrinkage of casting metal. The shrinkage of patterns and castings and the ceramic shell deformation depend on the properties of the pattern mass, casting metal, and ceramic shell material, and also on the casting shape, the process of pattern and shell production and the position of the pattern in the shell and of the casting in the mold. In machining the working cavity of a master die, allowances are specified for finishing operations to bring up the cavity to size after casting a pilot batch of products. The working cavity of a master die should be made to an accuracy which is 1 or 2 classes higher than the required accuracy of castings. The surface roughness of the die's working cavity is commonly not above the 8th class.

The correctly chosen die joint, drafts, and ejector pins provide for the removal of patterns from the die without causing any damage. The drafts should not be lower than 0.5°.

Pattern compositions. Investment patterns are prepared from mixtures of low-melting materials, commonly of the organic origin. The starting materials are paraffin, stearine, ceresin, lignite wax, peat bitumen, rosin, polystyrene, polyethylene, ethyl cellulose, and fatty acids.

Pattern compositions must have the following properties: a melting point at 60 to 100°C, the temperature of initial softening being 35 to 45°C above the temperature of mixture motion; minimum and stable linear shrinkage; minimum volume and linear expansion; good fluidity; sufficient strength and hardness to exclude damage to patterns; minimum ash content and freedom from adhesion to the surface of the die, tools, and to the hands of operators; and chemical inertness to the die materials and refractory coatings. Besides, the pattern compositions should not evolve noxious vapors under heat and in burning, be suitable for repeated use, and easily wettable by facing investment materials. The last but not least requirement is that the starting materials for pattern compounds must be cheap.

Depending on the requirements for dimensional accuracy and sur-

face finish of castings and the nature of production, foundries use low-melting pattern compositions based on plastics, and solvable and combustible compositions.

Low-melting pattern compositions find use for patterns of small relatively complex castings of the 5th, 6th, and 7th classes of accuracy. These compositions are commonly prepared from paraffin and stearine, most often in the proportion 1 to 1. The shortcomings of these compositions are a low softening temperature (54 or 55°C), small strength, and large shrinkage instability. A four-component composition which includes, along with paraffin, ceresin, lignite wax, and still residues, shows better properties, namely, increased strength and thermal stability.

High-melting pattern compositions are applicable in the production of thin-walled large-size castings of enhanced dimensional accuracy and surface finish. Most popular is the composition with 50% rosin, 30% polystyrene, and 20% ceresin. The shortcomings of this compound are low fluidity and the fact that it involves difficulties in its preparation.

Soluble pattern compositions are commonly based on urea with the additions of boric acid which acts as a plasticizer. In most frequent use is a liquid mixture containing 98% urea and 2% boric acid. The compositions are highly hygroscopic. An addition of up to 10% potassium nitrate decreases hygroscopicity.

Combustible pattern compositions are based on expanded polystyrene with the additions of plasticizers. Consumable patterns produced from these materials have high strength, low shrinkage (0.1 or 0.2%), and increased thermal stability, with the softening point above 80°C. The patterns are cast in master dies mounted on automatic machines. The burning polystyrene of expendable patterns produces much ash, which calls for special devices to keep the atmosphere against pollution.

Preparation of pattern compositions. The technology of production depends on the components which make up a particular compound. The degree of mechanization of the production process is determined by the output involved. Temperature-controlled ovens and various mixers find most extensive application.

Compounds consisting of paraffin and stearine are prepared in the following manner. The bars of stearine and paraffin are crushed, proportioned, and charged in strictly measured quantities into the pot of a melting unit. The compound is melted, heated to 80-85°C, and then stirred and left to stay for 15 to 20 min to allow the contaminants that have got into the solution to precipitate. The molten mass is poured into a mixer where the compound is cooled to a pasty state and saturated with air, the latter stage being necessary to decrease the shrinkage of the compound. The ready mass is conveyed to a receiver, from which it is delivered to the pattern shop.

A master die is filled with the molten mass by pouring, by injecting the compound in the pasty state, and by pouring and injecting under high pressure.

A common method for the production of patterns is to inject the pasty compound into the die cavity. Molding under pressure secures a higher dimensional accuracy and better surface finish of pat-

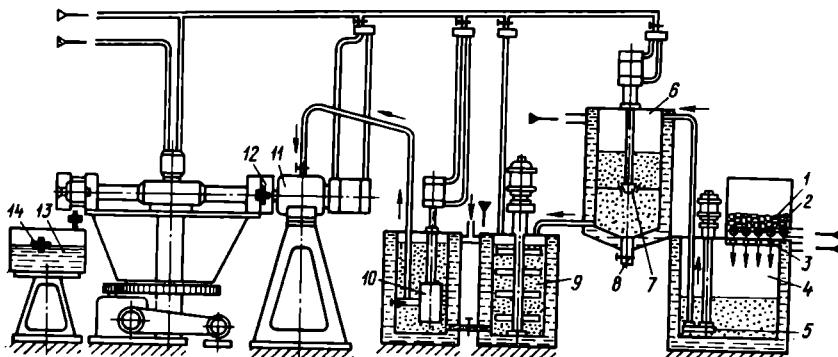


Fig. 213. Automatic installation for preparing a pattern mixture and production of patterns

terns. In an automatic installation used for the purpose machines prepare the paste from the molten mixture and inject it into master dies.

The grease for master dies consists of transformer oil or castor oil mixed with ethanol in the ratio of 1 to 1. In high-volume flow-line production, foundries use installations (Fig. 213) which automatically perform all the operations starting with the preparation of pattern mixes and ending with the injection of the paste into dies and molding of patterns. Pattern mixture ingredients 1 placed into a tank on water-heated tubes 2 melt and drip off through holes 3 into a tank 4, from which a pump 5 forces it into a tank 6. A measured quantity of the mix is then allowed to flow into a tank 9, with a valve 7 shut down.

Valve 8 serves to drain the pattern mixture, whenever necessary. In the tank 9 the mixture is brought to the required temperature and consistency and then transferred into a holding tank, from which a pump 10 delivers the mix to an injector 11 to force it into water-cooled dies 12 installed on a casting wheel. After the solidification of the mix, the die opens automatically to eject the pattern 14 into a cold water bath 13. The pattern cools further in the trough in which the stream of water carries the pattern to the pattern assembly room. Concurrent with the production of casting patterns, gating patterns (sprues

and cups) are cast. The patterns are then fixed to a central sprue to form a "tree" of patterns, as shown in Fig. 214, with an electrically heated hand tool having a tip in the form of a knife blade. This type of assembling of patterns into blocks is practiced in small-lot production.

In mass production, a casting pattern is cast integral with gating patterns in one and the same master die to form a single pattern piece. The pattern pieces are then built up into a pattern block, or assembly, in special installations.

4.3. PRODUCTION OF THE INVESTMENT MOLD¹

The stages involved in investment molding include pre-



Fig. 214. A 'tree' of investment patterns

paring the investment materials, forming a refractory ceramic shell on the pattern surface, melting the pattern from the shell, molding the shell in the investment, and calcining the mold.

The refractory ceramic shell must be sufficiently strong, deformable, gas permeable, chemically inert to metal, and easily collapsible after cooling of the casting.

The refractory materials used for forming an investment shell are silica flour, finely ground fused quartz, synthetic corundum, sillimanite, and others, and also quartz sands and ground fireclay. Powdered refractory materials serve for the preparation of a slurry of refractory investment (a refractory suspension) to form a primary coating on the pattern. The sands are used for dusting each layer of the refractory coat.

The binding agent most often used here is ethyl silicate, which is a complex chemical compound where orthosilicate containing 28 to 45% SiO₂ forms the base.

Preparing the initial materials. Silica flour and quartz sand are washed with water before use to remove clay constituents and then calcined at 950°C for 3 hours.

Ethyl silicate, (C₂H₅O)₄Si, is hydrolyzed to impart its bond-

ing properties. Acetone, ethyl aldehyde, and ethanol, C_2H_5OH , serve as solvents, and hydrochloric acid as a catalyst. The hydrolyzed solution of ethyl silicate is prepared in hydrolyzers made as propeller mixers. A hydrolyzer consists of two tanks inserted one into the other. The inner tank made in corrosion-resistant steel is intended for mixing ethyl silicate with ethanol. The outer tank is a water-cooling container for removal of heat liberated during ethyl silicate hydrolysis from the inner tank.

The hydrolysis of ethyl silicate is carried out in the following manner. The solvent and water diluted with sulfuric acid are poured into the hydrolyzer and stirred for 1 or 2 min. Next, stirring being continued, ethyl silicate is added gradually. The operation of mixing is not terminated until the solution cools down. The solution is then allowed to stand for 2 to 18 hours to accomplish the process of hydrolysis, which proceeds by the reaction



The reaction yields the gel of orthosilicic acid, H_2SiO_4 , which acts as a binder.

This is a separate method of ethyl silicate hydrolysis since the refractory material, such as silica flour, used to prepare the slurry of refractory investment is added after the hydrolysis reaction.

In use is also a *combined* method of hydrolysis; 1 kg of solution prepared by this method consists of 600 g ethyl silicate, 300 g ethanol, and 100 g water with 0.3 to 0.7% hydrochloric acid. The additions of silica flour vary in the range from 70 to 75% of the mass of solution.

In this case the hydrolyzer is filled with ethyl silicate and the solvent, and the ingredients are mixed for 1 or 2 min. Then two-thirds of the calculated quantity of silica flour is gradually added, and the ingredients are intermingled for another 2 or 3 min. Next water diluted with hydrochloric and sulfuric acids, is poured, and the slurry is stirred until it cools down. In this combined method, the hydrolysis reaction proceeds faster owing to a well developed surface of quartz particles, so that there is no need for holding of the solution after the hydrolysis. This method provides for a stronger investment shell than the separate method.

The refractory investment slurry is prepared in the mixer of the installation shown in Fig. 215. In the separate method of hydrolysis, the silica flour is poured into a mixer tank 1 and then the binder (the hydrolyzed solution of ethyl silicate) is added in the required proportion. The ingredients are mixed long enough to remove completely the air bubbles. The slurry so prepared is checked for viscosity, which should lie within 30 to 50, as tested on the B3-4 type viscometer.

Forming a ceramic shell. A pattern block 4 (see Fig. 215) is given a coat by dipping it, up to three times, in a refractory slurry and holding in the air after each dipping for 10 to 20 s. This operation is performed automatically. As seen, the pattern block 4 suspended from a holder that moves on a guide rail 2 of conveyor 3 dips into the bath of slurry, passes along and enters into a chamber 5 where quartz sand drops down and coats the pattern block. The pattern blocks are then placed in drying cabinets where they are held in the air for 4 to 6 hours at 18 to 20°C. Drying in the ammonia gas cuts down the holding time to 2 hours. After the second and the third dipping in the slurry, the shell is dusted with ground fireclay which has a lower coefficient of linear expansion. This helps decrease deformation of the ceramic shell on calcining, minimize the risk of shell cracking, increase the dimensional accuracy of castings, and form a strong shell from a minimum number of refractory layers, thus reducing the production costs.

After applying 3 to 4 or, sometimes, 5 refractory layers on the pattern block, the pattern mixture is removed from the shell by melting. For this the pattern block encased in the shell is heated in an electric chamber furnace, in hot water, or in the melt of a pattern composition. The compounds made up of paraffin and stearine, paraffin and ceresin, and also of paraffin and stearine with additions of ethyl cellulose can be melted from the shells by placing the pattern blocks in the melt of a pattern mixture. A certain amount of the pattern compound is lost as it drips away. The loss accounts for 5 to 10%. The remaining compound is reclaimed for repeated use.

Preparation of the mold. After removal of the low-melting compound, the shell is placed in a heat-resistant flask, which is then filled with an investment—dry quartz sand—poured from the hopper. The investment backing is rammed to give strength to the mold. Next the mold is preheated (calcined) before pouring in an electric or gas-fired oven at 900-1 000°C for about 2 hours.

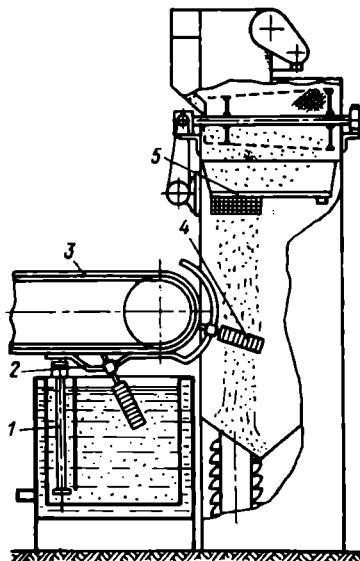


Fig. 215. Installation for coating patterns with slurry of refractory investment and dusting with refractory materials

4.4. INVESTMENT CASTING PROCESS

Alloys. Investment castings can be made from carbon steel, alloy steel, corrosion-resistant, heat-resistant and high-temperature steels, aluminum and copper alloys, and titanium. The investment casting process is most effective for the production of complicated shapes from difficult-to-machine alloys and steels.

Casting shapes. The investment casting process can produce castings of extremely complex shapes with the thickness of walls of about 1 mm. The process permits forming small holes in castings (up to 1.5 mm across in walls about 1.5 mm thick). In designing a casting, it is necessary to shape casting cavities in such a manner as to enable adequate injection of the pattern compound into the master die cavity, proper coating of the pattern with the refractory slurry and powdered materials, ready removal of the pattern compound from the ceramic shell and the ceramic residue from the casting cavities during cleaning.

It is expedient to produce large castings with thin flat walls from separate parts and then join them together by welding. On the contrary, compact case-type parts can be cast as a single unit. This simplifies the production process and facilitates the machining operations.

Gating systems. The quality of castings and the economic effectiveness of the investment casting process greatly depend on gating systems because about 30% of casting rejects result from inadequately designed sprues and gates. The gating system must comply with the following requirements: completely fill the mold with molten metal and supply metal during solidification to ensure a high casting yield; not disturb the dimensional accuracy of castings, that is, not cause distortion in the geometry of the castings as a result of shrinkage retardation; and provide for the manufacturability of the block of patterns and castings at all the production stages, including the fettling operation. The types of gating (Fig. 216) vary with the design of castings and the alloy being cast.

Type I gating system consists of a sprue and runners in the form of local thick portions or ingates that branch from the sprue (Fig. 216a, b). The sprue and runners here perform the function of risers, for which reason the massive sections of casting lie close to the sprue and runners. These gating systems are most popular for running small castings from steel and copper alloys.

Type II gating system consists of a sprue made in combination with local risers to feed individual massive members located at the top (Fig. 216c); the runners feed lower portions of the casting. Such a gating system is suitable for intricately shaped castings. Quiet gating from the bottom gives quality castings from the high-alloy steels and alloys.

Type III gating system constitutes a massive riser which serves at the same time as a metal receiver to provide for high pouring speeds (Fig. 216d). Such systems find use for casting screw propellers, rotors with blades, and other parts.

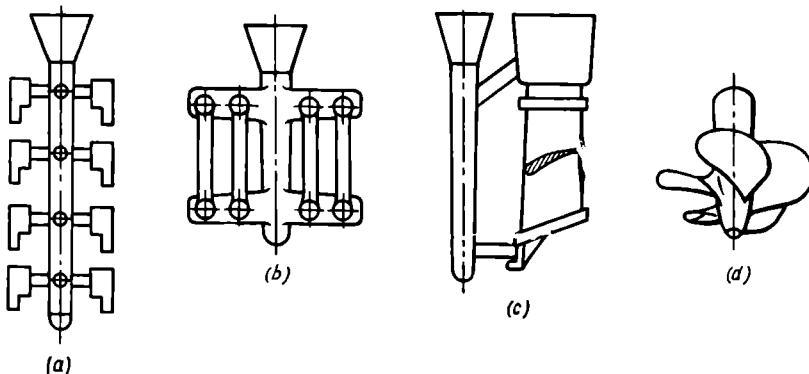


Fig. 216. Gating systems for investment castings

Calculation of gating systems for investment castings proceeds from the fact that a gating system must provide for progressive solidification of the casting. To produce a sound casting, the sprue should have a larger modulus of cooling (the ratio between the cross section and the perimeter) than a massive member of the casting. This ensures progressive solidification in the direction from the casting to the sprue. The length of a gate is specified depending on the type of cutting of castings from the sprue.

The dimensions of gating systems have been calculated for a large number of castings with due regard for the above requirements. The results have been checked in practice, corrected and summarized in a table, which is used in calculations (Table 64).

Example. Calculate the dimensions of the gating system for a steel casting of the 'loop' type 185 g in mass G (Fig. 217). Determine the modulus Z of cooling of the massive member which represents a bar of square cross section with a side a of 18 mm and length b of 40 mm.

The area of the cross section perpendicular to the metal flow is ab and the cross section perimeter is $2(a + b)$. Then

$$Z = \frac{ab}{2(a+b)} = \frac{18 \times 40}{2(18+40)} = 6.2 \text{ mm} \quad (30)$$

Assume the gate length l_g is 8 mm. According to Table 64, for $G = 185$ g and $Z = 6.7$ mm, the sprue diameter D_s is 45 mm and the modulus of cooling of the gate, δ_g , is 6.25 mm. As obvious from the calculation, the total dimensions of the casting do not allow us to dispose the gate with a modulus of cooling equal

Table 64
 D_s and δ_g versus Z and G

G, g	Parameter	Z, mm									
		1.1	1.8	2.5	3.0	3.5	3.9	4.2	4.6	5.1	5.8
<50	D_s , mm	20	20	25	25	30	—	—	—	—	—
	δ_g , mm: at $l=4$ mm	1.75	2.5	2.5	3.0	3.0	—	—	—	—	—
50-100	δ_g , mm: at $l=8$ mm	2.0	3.0	3.2	3.5	3.75	—	—	—	—	—
	D_s , mm	20	20	25	30	30	30	30	35	—	—
100-200	δ_g , mm: at $l=4$ mm	2.0	2.75	3.0	3.5	3.75	4.0	3.5	—	—	—
	δ_g , mm: at $l=8$ mm	2.5	3.5	3.75	3.5	4.3	4.75	5.0	4.5	—	—
100-200	D_s , mm	20	25	30	30	35	35	40	40	45	45
	δ_g , mm: at $l=4$ mm	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.5
	δ_g , mm: at $l=8$ mm	3.0	3.5	3.75	4.25	4.5	4.75	5.0	5.25	5.75	5.5
											6.25

to 6.25 mm since $\delta_g > Z$. So, it is necessary to decrease the gate length. We find from Table 64 that $l_g = 4$ mm and $\delta_g = 5.0$ mm at the same diameter of the

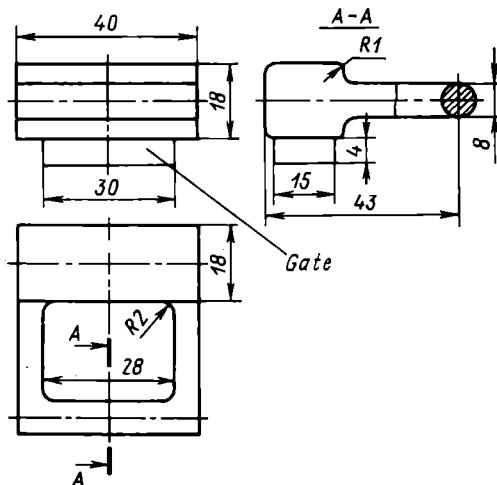


Fig. 217. Casting drawing

sprue. Finally we take it that $l_g = 4$ mm, $D_s = 45$ mm, $\delta_g = 5.0$ mm, and that the gate has a rectangular cross section with the sides that can be found from formula (30), assuming the gate thickness a_g is 15 mm. So, the side b_g is equal to 30 mm.

The gating elements such as sprues, gates, runners, and pouring cups are made to specifications.

4.5. MELTING AND POURING METAL INTO MOLDS, SHAKEOUT AND FETTLING OF CASTINGS

The metal for investment castings must meet the same requirements as in other casting methods, so that any of the foundry furnaces can be employed to melt the metal for investment castings. The process of melting the metal for pouring into investment molds does not commonly differ from other melting processes.

Pouring into molds. There are several methods of metal pouring. The choice depends on the size and mass of castings, alloy composition, method of mold production, and types of melting furnaces. Molten metal can be cast into the mold under gravity, under the forces of rotation on centrifugal casting machines, and at low pressure.

In casting high-temperature alloys containing easily oxidizable elements, oxide inclusions can contaminate the alloy during melting and pouring by the usual methods. These oxides decrease the strength properties and heat resistance of castings. Melting and pouring under vacuum or in a protective atmosphere can eliminate the above shortcomings.

Shakeout and fettling. After cooling of the molds, the castings are shaken out on special pneumatic knockout vibrators with the flasks inverted to remove the investment. In use are various facilities for removing sprues, gates, and flash from castings. These are vibratory installations, trimming presses, hack saws, circular saws, cutters, grinding machines, gas cutting torches, and electromachining cutting devices.

Cleaning of castings from ceramic residues. This is a labor-consuming fettling operation. Foundries use several methods of cleaning the castings from ceramic materials: vibratory, sand blasting, hydroblasting with the addition of sand, chemical heat treatment in the solutions of alkalis and acids and also in molten salts, and so on.

Alkalization is the widespread method of removing ceramic residues from castings. The parts contained in special baskets are placed into a bath with a 50% solution of KOH heated to 150°C. The alkali reacts with the ceramic skin and decomposes it in 30 to 40 min. The parts are then rinsed in hot water, dried, passivated in an aqueous solution of soda with 0.3% sodium nitrate, and dried again.

The stubs of gates are removed on emery grinders or semiautomatic grinding machines.

In annealing small steel castings, it is common to employ the process of normalizing in a protective atmosphere.

Chapter 5. SHELL CASTING

5.1. GENERAL

Shell casting is one of the precision casting processes which gives high surface finish and good dimensional accuracy to cast parts. Shell molds are prepared from resin-bonded sands using hot metallic patterns.

In the shell molding process (Fig. 218), a single-sided metal pattern plate 1 with metal patterns is heated to 200-300°C, coated with a parting mixture to keep the molding sand from adhering to the patterns, and placed on top of a dump box 2 with the patterns facing downward (Fig. 218a). The dump box with the molding sand-resin mixture is inverted (Fig. 218b) and kept in this position for 15 to 20 s. The resin particles melt and bond together the sand grains. In about 20 seconds the patterns become coated with a shell 3 of resin-

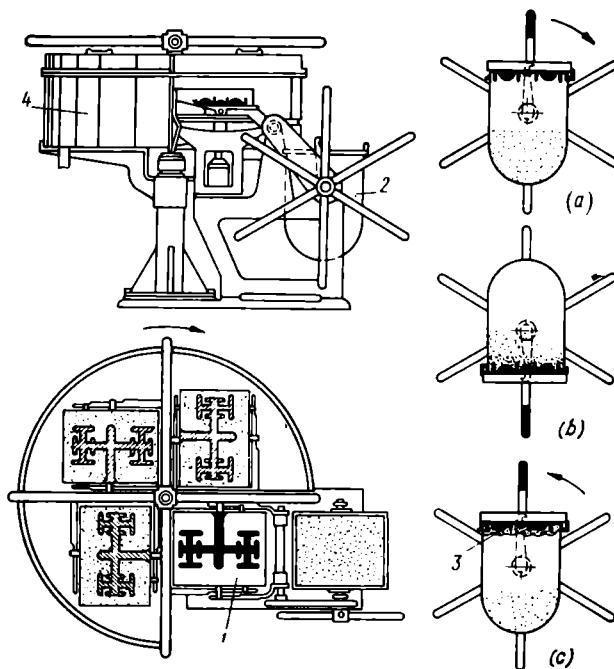


Fig. 218. Scheme of a shell molding process

bonded sand, following which the dump box is turned back to the initial position (Fig. 218c), so that the surplus of sand-resin mixture falls to the bottom of the dump box.

The pattern plate with the shell still adhering to it is removed from the box and transferred to an oven 4 for shell sintering at 230 to 400°C. In 30 to 300 seconds the shell hardens still further as a result of complete curing (polymerization) of the binder which gives the shell a high bending strength, 5 to 10 MPa.

The hardened shell is stripped from the pattern plate by ejector pins built into the plate. The two halves of the shell mold so produced are joined together by adhesives and fastened by various means, or placed in flasks which are then filled with a support material such as sand or metal shot. The mold is now ready to receive molten metal poured by any of the common methods.

Because the shell half-mold is removed from the pattern plate in the hardened state without rapping, its dimensions differ little from the dimensions of the pattern. Obviously, in this case the cast products have high accuracy of dimensions.

Along with the advantages such as good accuracy which allows decreasing the stock for machining by one half, and small consumption of molding sand, the shell molding process has its limitations. These lie in a high cost of molding mixtures and enhanced gas evolution of thermosetting resins, which necessitates installing high-power ventilation facilities. Moreover, the production of shell molds and cores requires complex and costly metal patterns. This method is economically feasible for large-production runs of castings. Shell molds permit producing parts up to 100 kg in mass and 800 mm in maximum size for cars, motocycles, and agricultural machines, and also castings from iron, common steel and alloy steel, and nonferrous alloys.

Pattern equipment. Patterns are made in aluminum, bronze, steel, and gray iron. They should be massive to keep heat required for shell formation. The best material for metal patterns is pearlitic gray iron. The wall thickness of patterns should be not less than 12 mm and that for pattern plates not below 15-20 mm. Pattern protrusions liable to fast cooling are made solid. Patterns and plates should have strengthening ribs with a thickness of walls coming to 70-100% of the pattern wall thickness. These ribs decrease the deformation of patterns and plates.

For easy removal of the shell from the plate, the vertical walls of patterns and core boxes are made with a taper of 0.5 to 1°. The drafts applied to core prints of patterns, gating patterns and core boxes range from 2 to 5°. The patterns must be 2 classes more accurate in surface finish than the castings. The ejector pins built into the plates should run about 3 mm short of the edges of vertical pattern walls around the external contour of the pattern in order to uniformly distribute the force applied to the shell while stripping it from the plate.

For small patterns it is enough to install 1 or 2 pins for every 100 cm² of the plate. The stroke of the pin is usually equal to the height of the pattern. Fig. 219 shows the construction of a pattern plate. It is good practice to make the mold joint flat. The machining allowances do not exceed 1 or 2 mm. Where casting needs only grinding, the tolerances lie at 0.25 to 0.5 mm.

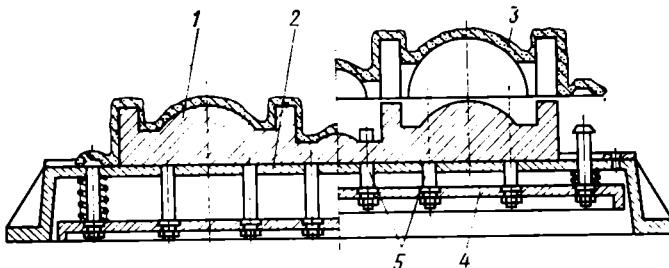


Fig. 219. Design of a pattern plate
1—pattern; 2—plate; 3—shell; 4—ejector pin plate; 5—ejector pins

Molding sands. These are mostly mixtures of fine-grained quartz sand (100% by mass) and powdered bakelite (6 or 7%). The mixtures can also contain small percentages of humidifiers such as kerosene or glycerin (0.2 to 0.5%) and solvents such as acetone, furfural, ethanol, and others (up to 1.5%). In the mass production of shell molds, use is made of bakelite-coated mixtures in which powdered bakelite uniformly distributed in the sand envelops the sand grains and thus improves the sand mixture properties such as the strength and gas permeability. There are two methods of coating the sand grains with bakelite, namely, the cold and the hot method.

With the method of *cold coating*, quartz sand is poured into the mixer and then the solution of powdered bakelite in acetone and ethyl aldehyde are added. The mixture consists of 90 to 92% quartz sand, 4 to 5% bakelite dust and 4 to 5% ethyl aldehyde.

During mixing of the ingredients, the resin envelops the sand grains and the solvent evaporates, leaving a thin film that uniformly coats the surface of sand grains, thereby imparting fluidity to the sand mixture. The method is simple, but requires a large quantity of solvent and good ventilation of the muller in its operation.

In the method of *hot coating*, the mixer is heated to 150-175°C prior to loading the sand. In the course of sand mixing, the soluble phenol formaldehyde resin (novolac) is added. The mixer goes on running until the temperature of the sand mixture drops to 80-90°C, following which the hardener urotropin is introduced. In three or four minutes of mixing, the mixture is discharged, cooled, and screened. This method is more complex, requires special equipment and

constant control over the mixture properties to prevent the resin from passing into the irreversible state. But the method gives better properties to the mixtures than the cold method.

The mixtures for shell molds are prepared in paddle, screw, and other mixers.

5.2. PRODUCTION OF SHELL MOLDS AND CORES

Shell molds are prepared by depositing a sand-resin mixture on the pattern plate from a turnover (dump) box or a stationary box, and also by sand blowing and sand shooting.

Parting mixtures are sprayed or brushed on the surface of plates to facilitate the subsequent removal of the shell from the pattern. The parting mixture can consist of 35 g heat-resistant silicone rubber per 1 000 cm³ white spirit—a solvent with a density of 0.795 g cm⁻³. The patterns coated with the parting oil (silicone oil) are heated for 1.5 to 2 hours at 200 to 220°C. A new layer of silicone oil is sprayed on to the pattern surface after every 15 to 20 shell strippings. The process of manufacture of shell half-molds consists of two stages, shell formation and hardening.

In the *first stage*, the thermosetting resin melts and envelops the sand grains. In the second stage, the resin irreversibly hardens, binding the sand grains into a solid mass. The machines (see Fig. 218) usually operate in combination with ovens which preliminarily heat up the pattern plate and then the shell mixture to cure the binder and thus impart hardness to the shell.

Production of shell cores. A low roughness of the surface of casting cavities produced with the aid of shell cores obviates in many cases subsequent machining. Shell cores are made in metal core boxes by variety of methods: by pouring sand into core boxes manually or mechanically, by sand blowing, and by centrifuging. The first method is analogous to the method of shell formation (Fig. 220), but a metal core box 2 set up on top of a dump box 1 replaces here a pattern plate. This method of shell core making uses core machines with turnover dump boxes.

The sand blowing method is adaptable to the production of more complex shell cores on special core machines.

The centrifugal method is used for the manufacture of cylindrical shell cores on centrifugal core-making machines (Fig. 221). A shell core is formed in a spinning core box, or mold, 1, rotated on a hollow shaft 3 by an electric motor 6 via V-belt transmission 5. The core box is heated in an oven 8.

A hopper 10 (position I) pours a measured quantity of core mixture into a trough 9 to make a core with a definite wall thickness. The trough then moves into a rotating box heated to 200-300°C through

a hole in the box cover, turns over and dumps the mixture (position II). As the trough returns to the initial position, a cylindrical heater moves inside the box to facilitate the shell hardening. The hardening being complete, the heater is removed, the electric motor deener-

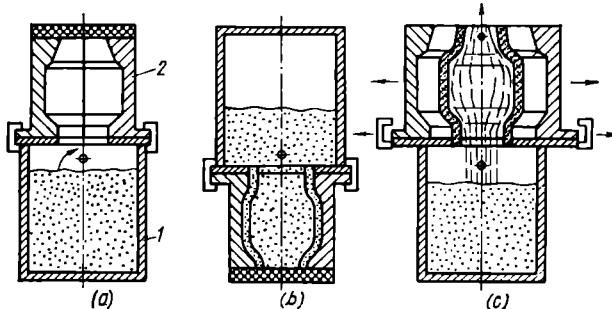


Fig. 220. Scheme of making a shell core

(a) placing of core box on a dump box; (b) shaping of core; (c) removal of core

gized, and a brake 7 is put in action to stop the box rotation. The finished core is forced out by an ejector 2 brought into motion by a push rod 4.

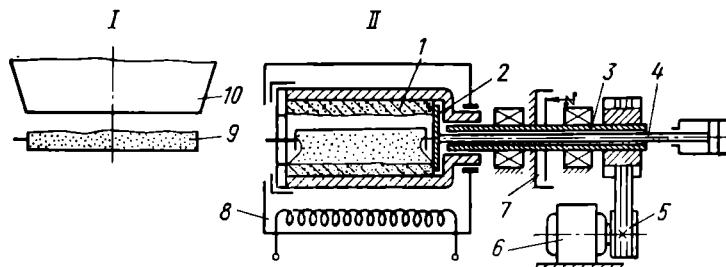


Fig. 221. Making a shell core by the centrifugal method

Large cores are made on single- and double-position machines, and small cylindrical cores on automatic machines.

5.3. ASSEMBLING AND POURING OF SHELL MOLDS. SHAKEOUT OF CASTINGS

Assembling and pouring of molds. The finished shell half-molds are joined together by adhesives, bolts and clamps. Fastening by means of bolts and clamps is the simplest, but rather labor-consuming and unproductive method. The most effective method is gluing shell

halves on special machines. Rather popular in practice are pin-type machines which pneumatically clamp shell halves for subsequent gluing by hand. Shell halves 1 (Fig. 222) fixed together with adhesive are placed into a special metal box 2, which is then filled with a support material 3, such as metal shot, to strengthen the mold. Where the shell becomes a complete mold without a support material, it is usual to fasten it with various means, for example, pneumatic clamps, to keep the shell from destruction during pouring.

Shakeout of castings. Drum-type shakeout installations are most widespread. Such an installation has a horizontal drum made of steel bars spaced 25 mm apart. The rotating drum is covered with a shroud to suck off the dust. Pneumatic pusher rods shift the cooled shell molds with castings from the conveyor (in the conveyor-type casting process) into a trough. The molds slide along into the rotating drum now set in a slightly inclined position. Shell pieces drop down into a hopper and then on to a belt conveyor which carries them to the dump site or to the reclamation shop. The castings stripped from the shells move along the trough and drop on a slat-type conveyor which delivers them to the fettling station.

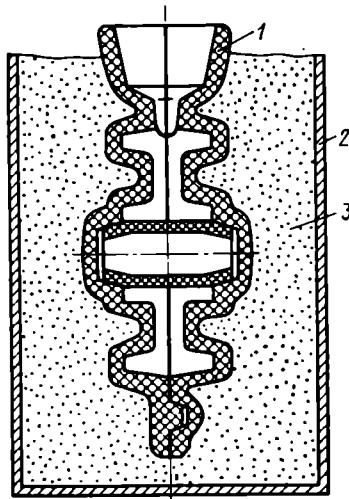


Fig. 222. Glued shell mold placed in a support box

Chapter 6. OTHER SPECIAL CASTING PROCESSES

6.1. CONTINUOUS CASTING

The principle of the process lies in the following. The liquid metal poured from the ladle into the tundish uniformly and continuously flows into a water-cooled mold, goes out at its lower end in the plastic state, where the rollers grip the metal and pull it out from the end of the mold at a controlled speed, rolling the solidifying metal into a variety of useful shapes (ingots, bars, tubes, billets of square, rectangular, or other cross sections).

By this process, it is possible to produce castings from any of the known ferrous and nonferrous alloys. The advantages that account for a high economic effectiveness of continuous casting are as follows:

- (1) production of ingots, tubes, and other shapes of unlimited length and required cross section;
- (2) increased casting yield due to a decrease in the amount of metal spent on the top and bottom parts of ingots;
- (3) reduction of labor and materials required for the production of dies;
- (4) decreased inhomogeneity of castings due to a lower segregation effect and elimination of shrinkage cavities and gas porosity.

There is a variety of continuous casting processes using vertical and horizontal continuous casting machines, where the product being cast moves in the horizontal or vertical direction. The vertical casting process finds more extensive uses.

A high quality of the metal of castings is achieved as a result of directional heat removal and thus progressive solidification of the product being cast. A continuous supply of liquid metal to the area of crystallization also adds to the positive effect. The castings and ingots are free from such defects as shrinkage and gas cavities and nonmetallic inclusions.

Production of pipes by the semicontinuous method is carried out on casting machines as shown in Fig. 223. A sand core, which serves to form a groove in a pipe bell 3, is set up on a bottom plate 1 with a dummy slab 2. Liquid metal is poured from a ladle 4 through a runner into a die 5, which is a thin-walled water-cooled mold. When the metal rises to the top of the mold, the plate gradually goes down, thereby pulling a solidifying pipe 6 from the end of the mold.

The plate reciprocates by means of an electric motor 7 via a suitable transmission mechanism. The speed of pulling the pipe from the mold must be such that the metal has enough time to solidify. The

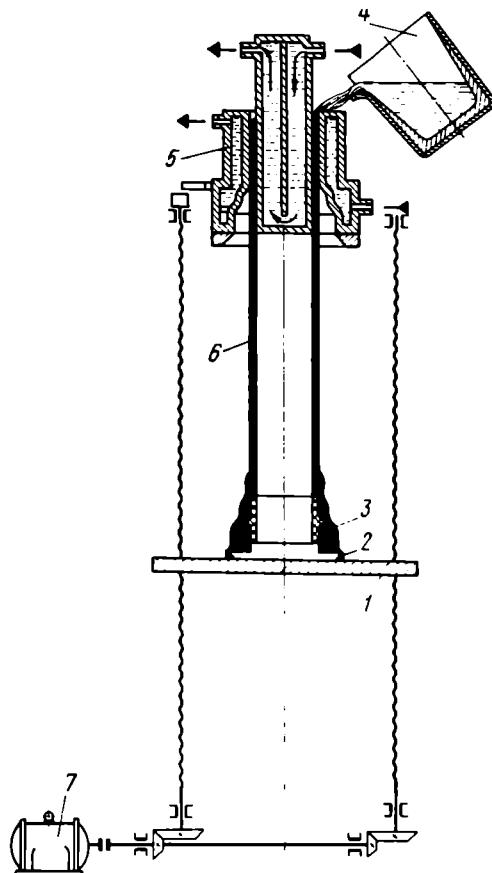


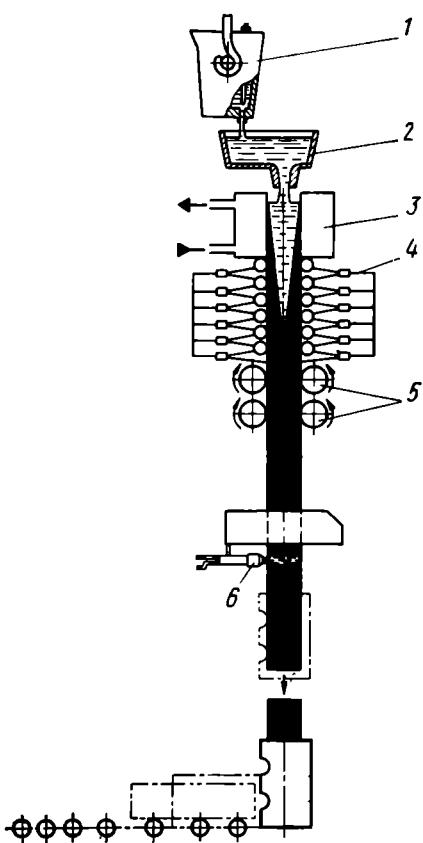
Fig. 223. Semicontinuous casting of bell-type pipes

pulling rate for tubes 10 to 12 mm in wall thickness is usually equal to 0.75-1 m/min.

Since the process permits progressive extraction of the pipe from the mold, the output of the casting plant is very high.

The process produces pipes of high quality as regards the surface finish and mechanical properties, which compare well with these characteristics for castings obtained in metal molds. This method is applicable for the production of pipes 0.8 m in diameter and up to 10 m in length.

Continuous casting of steel into ingots is a very effective method from the standpoint of economy. Fig. 224 shows the basic principle of a continuous-casting plant designed to cast steel into ingots 200



by 600 mm in cross section. Liquid steel is poured from a stopper ladle 1 into a tundish 2, from which it flows into a mold 3 with a dummy bar placed into the mold before pouring. The metal solidifies in the mold to produce a solid shell on the outside and the ingot bottom part that keeps fast to the dummy bar owing to a key-type bond formed between them. As the metal in the mold rises to a certain level, a special mechanism pulls the ingot by the dummy rod from the mold, the pulling speed being gradually raised to a specified rate. Primary rolls 5 draw the dummy rod with the ingot downward. Since the ingot pulled from the mold has a still mushy core, it passes through the zone 4 of secondary cooling where the sprays of water bring the ingot to complete solidification. As it passes through the withdraw-

Fig. 224. Principle of continuous casting of steel

wal-roll set, the ingot enters the carriage of a cutting device moving together with the hot ingot. A gas cutter 6 cuts off the ingots into billets. Roller conveyors then carry the billets for rolling.

6.2. CHILL CASTING[

In chill castings all or almost all carbon in the chilled layer is present in the form of cementite, Fe_3C , which is the hardest structural component. This structure gives the surface layer a high resistance to abrasion. Castings with a chilled surface layer find practical applications as grinding and crushing bodies such as tumbling balls, beaters in swing hammer crushers, and others. Castings with a white-iron surface layer can have a rather soft gray-iron central portion. This feature is of particular importance in the production of cast iron

rolls with the chilled surface for rolling mills. Other uses of such rolls are in the paper, flour, and other industries.

The basic difficulty involved in the production of castings with the chilled surface lies in obtaining the hard skin of definite thickness and hardness, which would smoothly merge into a mottled or gray-iron core.

The chilled layer must have a cementite-pearlite structure, the medium-hard intermediate layer a cementite-pearlite-graphite structure, and the core a pearlite-graphite structure.

The depth and hardness of chill depends on the following factors: the chemical composition and iron melting procedure, iron pouring temperature, material of the mold, type of mold facings and washes, and other influences.

The right choice of the chemical composition of an iron and the adequate conditions of its cooling can give the desired hardness and depth of chill.

The materials used for the production of chill castings include low-carbon and low-silicon irons whose composition depends on the hardness and chill depth specified and also on the strength properties required of castings.

As seen from Fig. 225, a chill casting has three distinctive zones: true-chilled layer I that extends from the surface inwards and ends with the appearance of the first traces of graphite; working layer II starting from the surface to the first traces of gray iron; and total layer III extending from the surface to the area where cementite inclusions disappear. The elements which make up the composition of iron differ in the effect each of them exerts on the hardness and the depth of chill.

An increase in the *carbon content* over 3% sharply diminishes the chill depth, for which reason it is impossible to control the chill depth by changing the content of carbon. Varying the silicon content helps accomplish the end.

The *silicon content* of chill castings does not commonly exceeds 0.5-1%; this percentage of silicon has no influence on the hardness of the chilled layer. But as the carbon content reaches 1.5%, the depth of chill sharply diminishes. *Manganese* exerts an opposite influence, but one should keep in mind the 'active' concentration of manganese in iron, that is, the difference Mn — 1.75% S. If this difference is smaller than 0.35%, the depth of chill decreases, and vice versa.

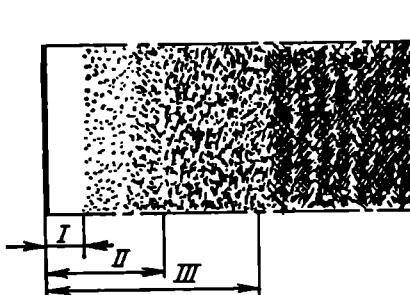


Fig. 225. Microstructure of a chilled roll

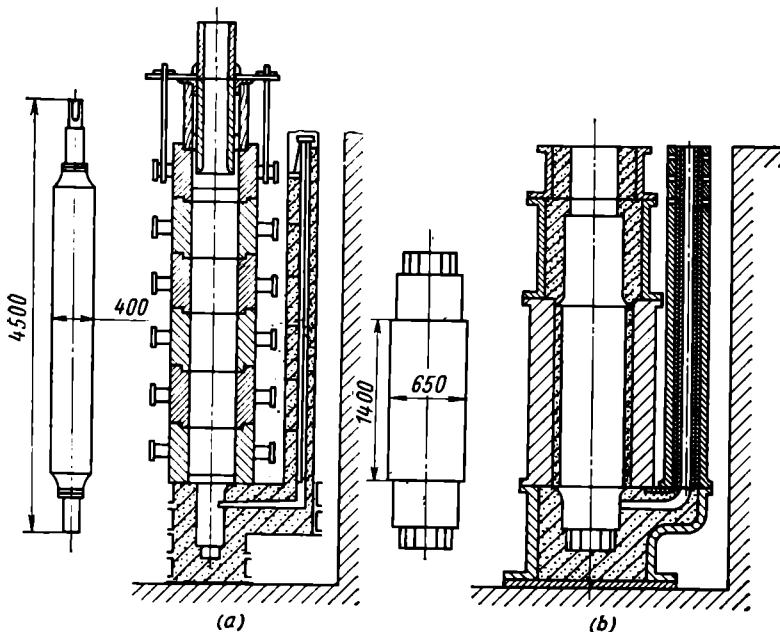


Fig. 226. Molds for casting hard rolls (a) and semihard rolls (b)

Phosphorus does not produce a noticeable effect on the depth of the chilled layer and its hardness.

Sulfur reduces somewhat the hardness of the chilled layer and sharply increases its depth.

Special additives such as nickel and chromium raise a little the chilled layer hardness. *Aluminum* acts in a manner similar to silicon.

Iron mill rolls. Iron rolls (both smooth and size rolls) come in semihard and hard types. Semihard rolls have the working layer of a pearlite-graphite structure. The structure of the chilled layer of hard rolls consists of cementite and pearlite.

Semihard mill rolls must have high strength and wear resistance, with the hardness of about 200 BH. These rolls are cast from low-carbon iron of the composition: 2.2-2.7% C, 0.5-1.2% Si, 0.5-1% Mn, 0.2-0.3% P, and 0.05-0.1% S. It is difficult to produce the iron of such a composition in cupolas. Reverberatory and, sometimes, open-hearth furnace fill the demand.

Hard rolls have a Brinell hardness of the chilled layer of 340 to 540. They are usually cast from an iron containing 2.6-3.0% C, 0.5-0.7% Si, 0.5-0.8% Mn, 0.2-0.4% P, and 0.07-0.12% S, and also from alloy irons with 0.7-1.5% Ni, 0.5-1.5% Cr, and 0.2-0.4% Mo. Section mills use globular-graphite iron rolls instead of steel rolls.

Semihard rolls are commonly molded with the aid of a sweep in two flasks (Fig. 226a). An iron semicircular flask is coated on the inside with a liquid solution of refractory clay so that the molding sand can adhere better to the flask. The molding sand is then poured into the flask and rammed. Next the mold is brought to size using the sweep and then finally covered with a liquid mass consisting of 50% coke dust, 30% used sand, and 20% fresh sand, the excess of the mass being struck off with the sweep. After drying, the mold is closed.

Hard mill rolls with a chilled layer are cast in permanent molds (Fig. 226b). The molds can be composite or made as a single piece. The inside surface of molds is coated with a refractory wash. The trunnions of rolls are cast in sand molds to exclude chilling. The pouring temperature of iron varies from 1 250 to 1 360°C depending on the chemical composition.

Longitudinal hot cracks appear in rolls with the chilled surface largely on account of a low strength and plasticity of the solidifying chilled layer. Since the graphitization of the central portion of the roll entails an increase in the metal volume, which induces tensile stresses in the chilled layer, the roll surface may crack in the longitudinal direction.

Rolls have a decreased tendency to develop cracks if the iron contains a strictly definite percentage of phosphorus. An increased content of phosphorus lengthens the stage of initial expansion of iron before shrinkage and thus prolongs the period of contact of the roll with the mold walls, with the result that the surface layers cool faster and become stronger.

To compensate for shrinkage of the roll, it is well to add feed metal to the riser during the roll solidification. The total quantity of feed metal comes to 5% of the mass of the casting.

After solidification, the rolls are left to cool in the molds to 200°C. Care should be taken to keep the finished castings from sharp cooling in the air, especially in the winter time.

6.3. CASTING BY SQUEEZING

The principle of the method. Liquid metal is poured into a metal receiver I (Fig. 227) of a special casting machine (stage I), then a movable half-mold is turned (stage II) so that the metal is squeezed to fill the cavity between the half-molds and jaws. As the mold closes completely, the distance between the half-molds corresponds to the thickness of the casting, the excess metal being squeezed out into a ladle (stage III). After solidification of the casting, the movable half-mold turns back to the initial position. The finished casting is then ejected from the stationary half-mold.

This method of casting is used for the production of thin-walled large-size parts of the panel type and shells measuring up to 1 000 ×

$\times 2\ 500 \times 3\ 000$ mm, with the wall thickness of 2.5 to 5 mm. These are parts of refrigerators, heat exchangers, and so on. The use of these single-piece cast units instead of riveted, stamped, and welded constructions built up of a large number of separate parts enables one to cut down sharply the time and labor required for the manufacture and assembling of similar units, and also improve their strength, rigidity, and resistance to vibration.

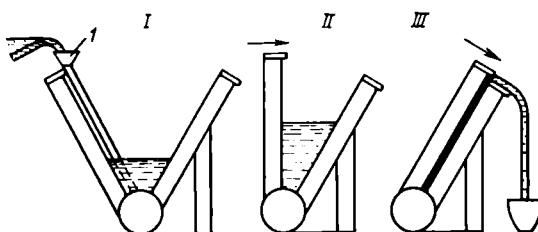


Fig. 227. Scheme of casting by squeezing

The materials used for such castings are commonly aluminum and magnesium alloys.

The casting-by-squeezing machines are complex automatic installations.

In some cases the two half-molds can be made of metal or sand. The choice depends on the design of a casting and the alloy used.

Metal half-molds are coated with permanent-mold washes before pouring and then heated to 250°C. The temperature of pouring aluminum and magnesium alloys into a metal receiver of the machine is usually 80-100°C above liquidus, and the temperature of squeezing is 20-40°C above the liquidus.

An important parameter of the casting process is the speed with which the metal rises in the mold. The optimal speed of metal flow is 0.5 to 0.7 m/s. At the end of squeezing, it is necessary to decrease the speed in order to preclude the ejection of metal from the mold.

The process is economically feasible in casting the parts that replace stamped and welded constructions.

6.4. LIQUID FORGING

Liquid metal forging is one of the variants of the crystallization of metals and alloys under piston pressure (Fig. 228). On exposing the metal to high pressures, 49 to 147 MPa (500 to 1 500 kgf cm⁻²), the plastic deformation of the solidifying casting closes the intercrystalline pores, compresses the gas-air voids, and precludes the isolation of gases dissolved in the metal during its crystallization. The

resultant casting has a high density. High rates of crystallization promote a finer-grained structure. All these factors improve the metal properties: the strength rises 1.2-1.5 times, and the percentage elongation and impact strength increase 2-4 times. The castings resemble forgings in properties.

Crystallization under piston pressure is used for the production of ingots and thick-walled shaped castings from various non-ferrous and ferrous metals and alloys.

The process employs both split and unsplit metal molds.

Liquid forging can be closed (Fig. 228a) and open (Fig. 228b). The melt is poured into a split or unsplit metal mold (Fig. 228c) to a certain level and then squeezed with a plunger at a speed of 0.1 to 0.5 m/s so that the metal fills the mold cavity. The pressure promotes better filling of the mold and increases the density of the metal.

The operating conditions of liquid forging depend on the properties of an alloy, the size and shape of a casting.

For alloys having a wide range of crystallization, the casting pressure is commonly 2 times as high as that for alloys with a narrow range of crystallization. The longer the time of holding of the alloy in the mold before applying the load and the thinner the walls of the casting, the higher must be the casting pressure. The temperature of metal pouring into the mold must be 50 to 100°C above the liquidus. An increase in the pouring temperature leads to the formation of shrinkage cavities, while a decrease in the temperature of pouring necessitates higher pressures. The plunger and the mold are heated before pouring to 180-250°C.

Because of a high cost of molds and an increased energy required for shaping of castings, this process is economically practicable in mass production.

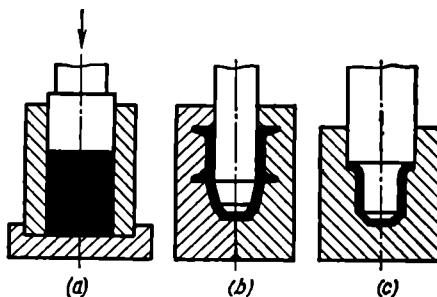


Fig. 228. Scheme of liquid metal forging

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